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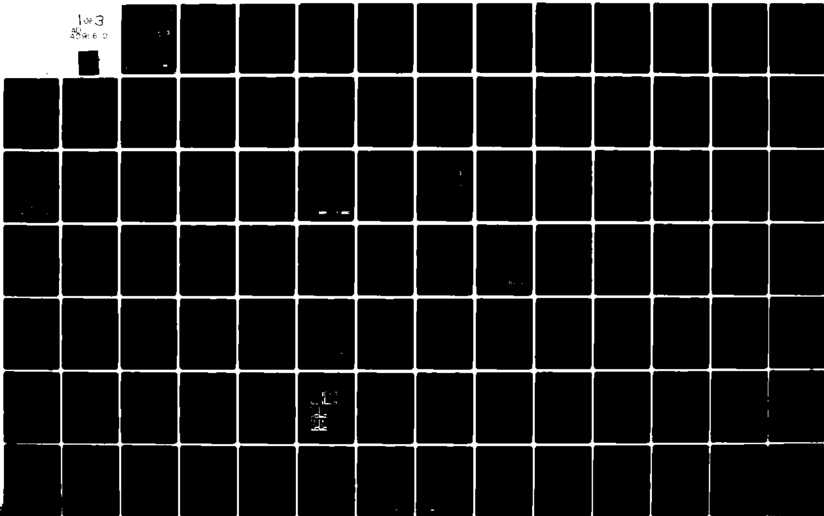

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# THERMOGRAPHY
# CONTROL OF HEAT INSULATION AND TIGHTNESS OF BUILDINGS

. Axen and B. Pettersson





UNITED STATES ARMY
CORPS OF ENGINEERS
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| Energy consumption | Heat transmission |
| Heat loss | Surface temperature |
| Heat radiation | Thermography |

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The purpose of this publication is to present the usefulness of the heat camera (IR camera) and its reliability for locating and charting deficiencies in insulation and tightness of completed buildings, and to indicate an appropriate procedure for routine application of the thermography method.

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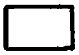
**DESIGNATIONS**

| | | | |
|---|---|---|---|
| | Energy consumption | | kWh |
| E | Energy flow per surface unit | | $W/m^2$ |
| $\Delta$ I | Delta, isoterm units between two isoterm markings | | |
| M | Heat resistance in construction | | $m^2 \cdot K/W$ |
| $M_{tot}$ | Total heat resistance | | $m^2 \cdot K/W$ |
| $m_i$ | Heat transfer resistance for the inside of the construction | | $m^2 \cdot K/W$ |
| $m_u$ | Heat transfer resistance for the outside of the construction | | $m^2 \cdot K/W$ |
| $\underline{a}$ | Heat transfer coefficient | | $W/(m^2 \cdot K)$ |
| $\underline{a}_i - 1/m_i$ | Heat transfer coefficient for the inside of the construction | | $W/(m^2 \cdot K)$ |
| $\underline{a}_u - 1/m_u$ | Heat transfer coefficient for the outside of the construction | | $W/(m^2 \cdot K)$ |
| k | Heat penetration coefficient | | $W/(m^2 \cdot K)$ |
| | | alt. | $W/(m^2 \cdot °C)$ |
| $P_i$ | Air pressure on the inside wall | | Pa |
| $P_u$ | Air pressure on the outside wall | | Pa |
| $\Delta p = p_i - p_u$ | Delta, air pressure indoors/outdoors | | Pa |
| p | Static pressure | | Pa |
| q | Heat flow density | | $W/m^2$ |
| T | Thermodynamic temperature | | K |
| t | Temperature | | °C |
| $t_{ref}$ | Reference temperature | | °C |
| $t_i$ | Indoor temperature | | °C |
| $T_{vi}$ | Surface temperature on the inside of the construction | | °C |
| $t_u$ | Outdoor temperature | | °C |
| $t_{vu}$ | Surface temperature, construction outside | | °C |
| $\Delta$ t | Temperature difference, corresponding to the isoterm difference in the thermogram | | °C |
| $\lambda$ | Wavelength (radiation) | | µm |
| $C_s$ | Radiation constant for absolutely black surface | | $5.775\ W/(M^2 \cdot K)$ |
| c | Speed of light | | $3 \cdot 10^8$ m/s |
| g | Gravity acceleration | | $9.81\ m/s^2$ |
| h | Planck's constant | | $6.63 \cdot 10^{-34}\ Ws^2$ |
| k | Boltzmann's constant | | $1.38 \cdot 10^{-23}$ Ws/K |
| $\underline{\sigma}$ | Stefan & Boltzmann's constant | | $5.7 \cdot 10^{-8}\ W/(m^2 \cdot K^4)$ |
| $\underline{a}$ | Absorbence | | 1 |
| $\underline{r}$ | Transmittance | | 1 |
| $\underline{p}$ | Reflectance | | 1 |
| $\underline{e}$ | Emittance | | 1 |
| $\underline{p}$ | Density | | $kg/m^3$ |
| v | Wind speed | | m/s |

| | | |
|---|---|---|
| c | Specific heat capacity | J/(kg · K) |
|  | Heat camera | |
|  | Concrete | |
|  | Light concrete | |
|  | Light clinker | |
|  | Heat insulation | |
| | Error marking | |

# 1. INTRODUCTION

## 1.1. General

Recently, the demand for energy saving constructions has increased significantly. The development in the energy field, in combination with the requirements for good indoor climate, has made it necessary to pay increasingly great attention to the performance of the heat insulation and air tightness of the building as well as the efficiency of its heating and ventilation system.

In the Swedish Building Norms, SBN 1975, 3rd ed., the national planning office (Statens planverk) has introduced new rules and regulations concerning energy conservation in buildings, which require highly insulated and tight constructions. In the areas of workmanship and supervision, the testing and control requirements have been made more stringent, as applied both to laboratory and to field measurements. There is a great need of appropriate testing methods to control the heat insulation and tightness of buildings.

In highly insulated and tight constructions, deficiencies in the insulation and tightness performance may have a great influence on the energy losses. Errors in the heat insulation and air tightness of the building do not only go hand in hand with a risk of too high heating and maintenance costs, but they also create the preconditions for an unpleasant indoor climate.

Currently, no well documented information is available concerning how much insulation deficiencies and air leakage contribute to increased annual energy consumption. However, results from various investigations indicate that such deficiencies are very common, even in newly constructed residences, and that their influence on the energy consumption is very great.

The insulation level of a building is frequently identified in the form of a heat resistance or heat penetration coefficient (k value) for the various parts of the building. However, the indicated heat resistance values seldom constitute a measure of the real energy losses in a building. Air leakage through joints and connections as well as insufficient filling of insulation material will frequently cause considerable deviations from the dimensional and expected values.

Laboratory testing will verify the specified characteristics of individual materials and construction parts. In order to ascertain that the intended insulation and tightness function of the building has really been fulfilled, it is necessary to verify this by means of testing and control in the completed building.

During the past several years, investigations have been performed in Sweden to develop a method for routine control of insulation and tightness performance in buildings by means of so called <u>thermography</u>. With the aid of this method, the temperature distribution (actually, the temperature radiation) of surfaces can be determined and depicted.

In construction technology applications, thermography is used to study temperature variations along the surfaces of the building. Under certain conditions, variations in the heat resistance of the construction cause temperature variations on its surfaces. Leakage of cold (or warm) air through the construction also influences the distribution of surface temperature. This creates a possibility to located and chart deficiencies in the insulation, cold bridges, and air leakage in the construction parts enclosing the building.

The thermography method does not directly indicate the heat resistance or air tightness of the construction. In cases when a quantification of the heat resistance or the air tightness would be desired, supplementary measurements must be performed In thermography of buildings, there are certain prerequisites in respect to temperature and pressure conditions throughout the construction.

Details, shapes, and contrasts in the heat image can vary considerably if certain parameters are changed. An in-depth analysis and interpretation of the heat image thus requires good knowledge of e.g. material and construction characteristics, climate influence, and up-to-date measuring techniques. In the evaluation of the measurement results, certain competency and experience requirements have been stated for the measurement personnel, e.g. an authorization from the national testing institute (Statens Provningsanstalt).

The basic principles for thermography of buildings have been previously investigated by the national testing institute. Some of these efforts have been reported in a publication from Byggforskningen (Building Research), by Paljak and Pettersson (1972). In this publication, containing mainly measurements performed in a laboratory setting, suggestions are presented for interpretation guidelines referring to heat images. The studies on which the present report are based have predominantly been performed in the field, i.e. in completed buildings. This report offers a more detailed treatment of e.g. influential parameters, measuring conditions, interpretation procedure, and it also includes practical examples from the thermography work, such as systematic errors in the heat insulation and air tightness of buildings.

## 1.2. Content Overview

The purpose of the present publication is to present the usefulness of the heat camera (IR camera) and its reliability for locating and charting deficiencies in insulation and tightness of completed buildings, and to indicate an appropriate procedure for routine application of the thermography method.

After the introductory Chapter 1, Chapter 2 gives a general presentation of energy consumption and energy requirements as well as testing and control of buildings. An overview is given, surveying different methods for verification of insulation and tightness of buildings. The section is concluded with an evaluation of the effects of efficient testing and control on the insulation and tightness of buildings.

Chapter 3 treats the influence of various parameters in thermography of buildings. A short description is given of the principle of the heat camera. The section describes heat radiation and explains how the emitting, reflecting, and transmitting characteristics of the surface influence the potential of the heat camera to correctly represent the temperature of the surface. This section also treats the correlation between surface temperature and heat resistance. Further, there is a presentation of the influence of variable conditions, such as weind, heat transfer resistance, temperature, and sun on the heat image.

In Chapter 4, requirements are stated for measuring conditions to be met in thermography of buildings. The section contains rules for and examples of thermogram interpretation as well as utilization of comparative thermograms. The importance of correct camera adjustment for achieving high quality heat images and thermograms is touched upon. The section also treats the reliability of the measuring method, i.e. if it is possible to locate and identify errors in insulation and tightness of buildings with sufficient precision. Examples of thermography result verification are given.

In Chapter 5, the authors provide examples of a number of comparative thermograms of common deficiencies in the insulation and tightness of buildings. The purpose of the comparative thermograms is to facilitate interpretation and evaluation of thermograms from the field.

Chapter 6 contains examples of practical cases where certain constructions and construction details have been studied.

Chapter 7 exemplifies the efficiency of improvements made where certain types of insulation and tightness deficiencies have been found.

In Chapter 8, there is a presentation of systematic errors in heat insulation and air tightness found in certain construction types. The investigation covers approximately 400 projects, corresponding to approximately 3,000 residences in single or multiple dwellings. The projects are geographically distributed over the entire country.

Chapter 9 reports certain technological experiences of construction, materials, and workmanship. The section presents instructions in measurement techniques and appropriate procedure for thermography of buildings. Chapter 10 contains a short presentation of the development of thermography.

# 2. ENERGY CONSUMPTION AND TESTING

## 2.1. Energy consumption in Sweden

In the years 1953 - 73, our total energy consumption increased by between 5% and 6% annually. In 1973, we were affected by the so called oil crisis, which significantly changed the situation of the oil-consuming industrialized countries. The limited supply of cheap and easily accessibly energy became obvious. The energy consumption after 1973 is characterized by a temporary decrease in 1974, whereafter the consumption increased again. The rate of consumption increase from 1975 does not tend to slow down as compared with that applicable to the period prior to 1973. The total energy consumption in the country for the year 1975 amounts to approximately 440 TWh ($440 \cdot 10^9$ kWh), according to the Central Bureau of Statistics (SCB).

The decision by the Swedish parliament in 1975 in respect to energy policy means that the rate of increase for the total energy consumption must be limited to an average of 2% annually through 1985. From the early 1990's, the energy consumption is to be maintained at a stationary level. For the residential sector, this energy policy sets the goal of decreasing the consumption by an average of 0.9% per year for the period 1975-85 in spite of the fact that the total number of residences is expected to increase in the future.

The energy consumption is usually divided over three sectors: industry, communications, and other uses. For the last several years, the distribution between the various sectors has been fairly permanent. Approximately 40% goes to industry, approximately 20% for communications, and approximately 40% to other uses.

In the "other uses" sector, the major portion (approximately 96%) of the energy is used for local comfort, i.e. heating, ventilation, illumination, etc. in residences and other facilities, such as care-taking institutions, hospitals, offices, schools, and vacation homes.

Since almost helf of the national energy consumption is represented by local comfort, the "other uses" sector is of great interest in evaluation of energy saving actions. The energy consumption for residences is distributed with approximately 54% for single family dwellings and approximately 46% for multiple dwellings.

## 2.2. Energy consumption in a building

The energy losses in a building can be classified into the following major loss groups:

- Transmission through the surfaces enclosing the building

- Ventilation, subdivided into desirable effect by means of ventilation equipment, etc., and undesirable effects due to leaks in the building.

In addition, energy is also consumed for hot water, kitchen appliances, etc., which can partially be regained on the heating side.

The major investigations in the energy field have included estimations of annual heat losses in existing buildings. The following values have been estimated (SOU 1977:56).

| | | |
|---|---|---|
| Residences | Single and multiple dwellings | ≈ 100 TWh/year |
| Facilities | Industrial facilities | ≈ 25 TWh/year |
| | Other facilities | ≈ 50 TWh/year. |

FIGURE 1 shows an example of energy consumption in a single family dwelling according to the construction method common in the early 1970's. To determine the ventilation, 0.8 air changes per hour have been assumed in the example.

FIGURE 1: Transmission and ventilation losses in a single family dwelling with an area of 125 $m^2$, insulated according to the standards of the early 1970's.

| | |
|---|---|
| Transmission losses | 16,500 kWh |
| Ventilation losses | 9,500 kWh |
| TOTAL | 26,000 kWh |

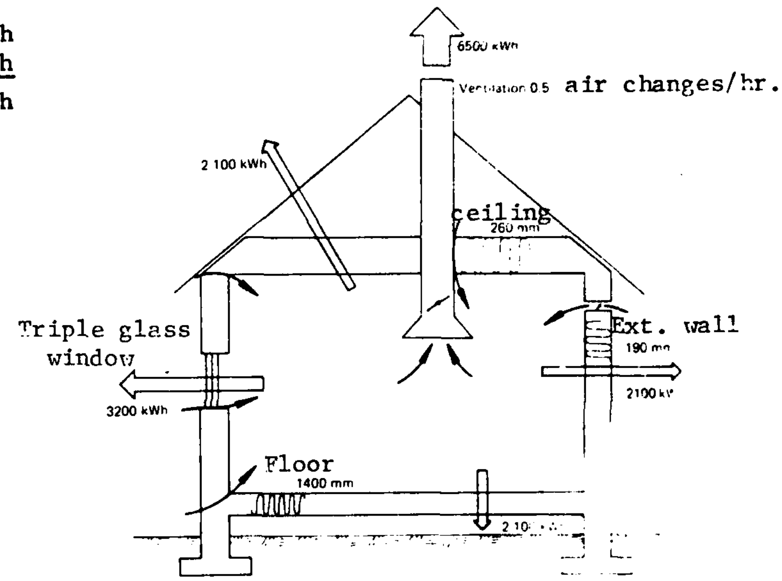


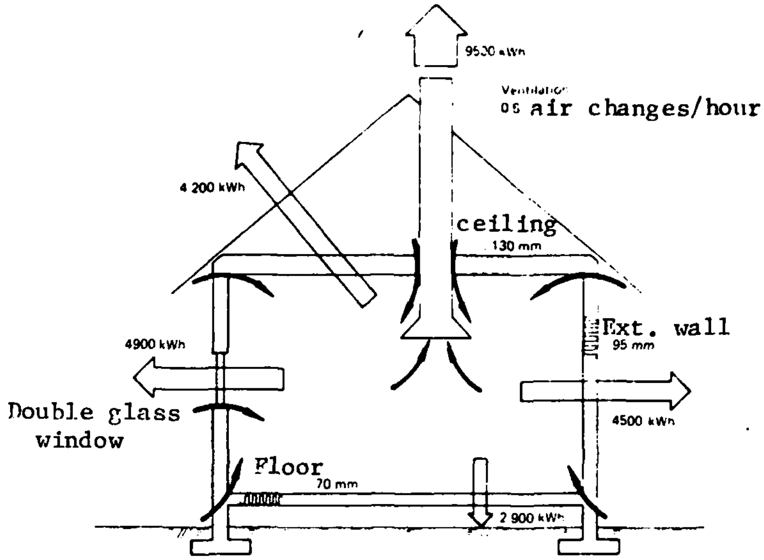

FIGURE 2 shows an example of energy consumption in a corresponding single family dwelling insulated according to the new requirements indicated in SBN 1975 /16/. As can be seen, the level of insulation capacity has increased considerably. The ventilation has been assumed at 0.5 air changes per hour.

The transmission losses are theoretically determined by the heat resistance or the k-value of the different construction components. In calculating the heat resistance of a construction, the goal is to achieve a desirable indoor climate from the standpoint of the outdoor climate. For this purpose, some type of "climatizing" is required, e.g. heating and ventilation.

The transmission and ventilation losses calculated in Figures 1 and 2 apply for an error-free construction. Experience has shown that deficiencies in insulation and tightness frequently cause significant deviations from the expected energy consumption in a building.

<u>FIGURE 2</u>: Transmission and ventilation losses in a single family dwelling with an area of 125 $m^2$ and insulated according to the requirements stated in SBN 1975.

| | |
|---|---|
| Transmission losses | 9,500 kWh |
| Ventilation losses | 6,500 kWh |
| TOTAL | 16,000 kWh |




The basic prerequisite for practically achieving an optimal level of insulation and itghtness is that the proper dimensional guidelines are followed and that the estimates of energy price and cost development are correct. However, the vital factor is to really achieve the desired functions of insulation and tightness. Here, the important considerations are the construction techniques, material selection, and workmanship. This is particularly important for highly insulated and tight constructions, since the relative effect of errors is greater in this type of buildings than in buildings with a lower degree of insulation and tightness requirements.

## 2.3. Requirements and guidelines according to SBN 1975

### 2.3.1. Heat insulation and air tightness

Swedish Building Norms, SBN 1975, states certain general requirements on the heat insulation and air tightness of house constructions (Chapter 33:1):

"A building purported to be heated shall be heat insulated and sealed so that no hygienic disadvantages occur and so that the heat loss and air leakage through the enclosing portions are limited in accordance with the requirement for good energy management."

Regarding the air tightness of buildings, it is stipulated (Chapter 33:3):

"Building portions which separate a facility to be heated and which connect such building areas are to be so constructed that undesirable air leakage is prevented."

For construction design, it is stated (Chapter 33:4):

"Heat insulating building components and connections between such components are to be arranged so that no air flow will occur in the construction components which would unfavorably affect the heat insulation capacity. Further, the construction is to be arranged so that the moisture level of the construction materials will not be such that it can jeopardize the function and permanence of these. Furthermore, the construction is to be designed so that no undesirable cold bridges will occur."

In the building norms, these regulations are supplemented with the maximum permissible values for air tightness and k-value both for building components and for completed buildings.

### 2.3.2. Testing and control

One result of the strict demands on construction quality due to the energy consumption aspects is that testing and control have become significant in order to ascertain the expected functional levels.

SBN 1975, Chapter 33:5, contains the following regulation for workmanship and supervision:

"Heat insulating building components are to be manufactured and assembled according to approved documentation and under the supervision of the responsible foreman. The responsible foreman is required to control, by inspection of insulation, joints, etc., that the workmanship is satisfactory.

Control of air tightness in a completed construction will be achieved by spot checks. Furthermore, there will be a special control of heat insulation and air tightness in a completed building if there is any doubt that the workmanship has been satisfactory, and if the building authorities deem such a control justifiable."

In the comments to SBN 1977:3, Energy management etc., Chapter 33:5K contains the following concerning special control of air tightness and heat insulation:

"Special control of heat insulation or air tightness will be performed when there is a reason to suspect that satisfactory workmanship has not been achieved in respect to heat insulation capacity or tightness. One such reason may be that satisfactory results have not been obtained in the regular tightness testing according to the above; in such cases, the building authorities can require testing measures beyond those initially anticipated.

"Another reason may be that it has been found during inspection that insulation or tightness do not meet the requirements.

"Special testing of the air tightness will be performed according to the methods and guidelines of the regular tightness control as indicated above.

"Air leakage can be traced with a heat camera.

"Special control of heat insulation can be performed according to one of the following methods:

a) Evaluation of the heat insulation performance by thermography and heat camera.

b) Measurement of the heat insulation capacity in critical locations by means of heat resistance measurement.

c) Disassembling the construction at critical locations and visual inspection of the heat insulation quality."

## 2.4. Effect of testing and control

It may be difficult to anticipate the functioning of heat insulation and air tightness in a completed building. In the assembly of the various components at the site, there are incidents that can greatly affect the final result. It is impossible to make advance caluclations of the effects of transportation, handling, and storage at the site as well as of the workmanship. In order to ascertain the actual achievement of the desired function, it is necessary to verify this by means of testing and control in the completed building.

Given the current state of the art of insulation technology, the theoretical heat requirement has decreased as compared with earlier conditions. However, this means that relatively minor errors, - but at critical locations - such as leaking joints or insufficient filling with insulation material, may have grave consequences from the standpoints of both heat and comfort. Verification tests by means of e.g. thermography have proven to be valuable from several points of view, that of the planner and entrepreneur, the builder, the building administration, and the user.

For the planner, it is of importance to be familiar with the function of various construction types so that these can be designed with an eye to both work methods and functional requirements. The planner must also know the practical functions of various materials and material combinations. Efficient testing and control in combination with appropriate feedback can contribute to desirable developments in these areas.

For the entrepreneur, expanded testing and control measures are vital in order to ascertain that the constructions fulfill the required functions in accordance with official regulations and contract documents. At an early stage in the construction, the entrepreneur needs information concerning potential changes to be made in order to prevent system errors. Thus, the control in the construction stage should be performed in the first apartments to be finished in a serial production. This control will then be followed up in the continued construction activity. In this manner, system errors can be prevented and unnecessary costs can be avoided, as can future problems. This control is to the advantage of both producer and user.

For the builder and the building administrator it is necessary to test the buildings from the standpoints of heat economy, maintenance (moisture or leakage damages), and resident comfort (e.g. cold surfaces and air movements in the living areas).

For the user, it is a major concern that the completed product will conform with the promised standards of heat insulation and air tightness. Buying

a house is a major financial responsibility for a private person. Thus, such a person is interested in knowing that potential construction errors do not cause serious financial consequences or hygienic discomforts.

In the inspection procedure currently used, the buyer has the opportunity to be present at the final inspection (when taking up residence and at the warranty inspection approximately one or two years later). The inspection is performed by a specially appointed inspector. It is very difficult to evaluate the insulation and tightness of the building visually, and this type of inspections will mainly focus on obvious error and so-called imperfections in appearance. It is possible that hidden, serious errors are not discovered in the inspection but may lead to serious consequences for the user.

The effect of testing and control of the heat insulation of the building is both phsyiological and economical.

The physiological experience of the indoor climate is very individual. It will vary depending on the differences between individuals in respect to the heat balance and temperature impressions of the human bodies. Both the temperature of the air in the room and the temperature of the surrounding surfaces will affect the experience of the indoor climate. The movement and humidity of the air in the room are also significant. Physiologically, the feeling of a draft means a local cooling of a body surface, caused by:

- too great air movements in the living zone with normal air temperature

- normal air movements in the living zone with too low air temperature

- major radiation heat exchange with a cold surface.

The quantitative effect of testing and control of heat insulation and air tightness in a building is difficult to evaluate. However, the following knowledge has been gained in the course of the investigations:

In a great number of cases, the costs for correcting errors in the insulation and tightness have amounted to between 3,000 and 5,000 SCr per house or more, if the errors have not been discovered until the house has been completed and the owner has moved in. Testing and control must be introduced at the beginning of a construction stage. They should be far-reaching enough so that system errors can be detected and corrected at an early stage. Examples have shown that the costs for such measures and changes can be brought down to a very low level. Spot checks in a number of small houses or apartments may bring a noticeable effect even without testing all units. In those cases where thermography has been prescribed in the contract as a control method, it has been possible to notice a remarkable quality improvement as compared to the average.

Studies have shown that deficiencies of heat insulation and air tightness are frequently discovered, which would correspond to a heat loss increase of 20 - 30% as compared with the expected situation. This has also been confirmed by means of follow-up of energy consumption before and after action in relatively vast tracts of small single homes as well as in multiple dwellings. Probably, these figures are not characteristic for the great number of buildings in general, since the background material of the study is not representative for the total supply of residences. However, a careful estimate would be that efficient testing and control of the heat insulation and tightness of the building would result in an energy saving of no less than approximately 10%.

Studies have also shown that increased energy consumption in conjunction with malfunctioning is frequently caused by residents raising the indoor

temperature one or more degrees above the normal in order to compensate for the unpleasant effect of heat radiation towards cold surfaces or a feeling of disturbing air movement in the room.

## 2.5. Methods and aids for controlling insulation and tightness

Deficiencies in the heat insulation and tightness of buildings can be discovered from abnormally high heating costs and uncomfortable indoor climate.

In the following, we will indicate those methods which can be used to verify the magnitudes affecting the energy losses and the climate in a building, see Table 1. With the exception of the soap bubble method, all methods have been tested in conjunction with the present investigation.

### A. Measurement of surface temperature

#### 1. Thermography

| | |
|---|---|
| Instrument | Heat camera, surface thermometer, manometer, and air speed meter |
| Measurement precision | ± 0.5 °C or ± 10% of the measured temperature difference |
| Principle | Record thermal radiation within the wavelength area 2.0 - 5.6 μm<br>Measures and depicts the radiation distribution over a surface |
| Method | The distribution of heat resistance as well as the insulation and tightness standards are evaluated from illustration and charting of the surface temperature distribution (SIS 024210) |
| Application area | Complete building: construction components, joints, module edges, and connections. |

Advantages:
The method is rapid and gives a good overview picture of the temperature distribution in the temperature radiation from a large surface area.
Measurements are possible in areas which are not easily accessible. There is no disturbing contact between the instrument and the object of measurement.
An image is obtained of the insulation and tightness standard of the construction.
By means of the heat camera, it is possible to locate and chart insulation deficiencies, air leakages, and cold bridges in the construction.
The method is pedagogical. Results from thermography studies are suitable for use when giving experience feedback.
(Excellent complement when pressure measurement and heat flow measurements are performed.)

Limitations:
The method is qualitative and gives no direct value for the heat resistance and the k-value.

**TABLE 1:** Summary of various methods that can be used for verification of insulation and tighness quality of buildings

| Characteristics | Thermography | Surface (air) temp. meas. | Radiation meas. | Heat flow meas. | Gas tracing method | Pressure method | Air speed meas. | Smoke gas test | Soap bubble method | Disassembly | Drawing control |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Heat resistance | 1 | 1 | 1 | 2 | - | - | - | - | - | 1 | 1 |
| Insulation quality | 2 | 1 | 1 | 1 | - | - | - | - | - | 2 | - |
| Air tightness per SBN 1975 | 1 | - | - | - | 0 | 2 | 0 | 0 | - | 0 | 0 |
| Tightness, workmanship | 2 | 0 | 0 | - | 1 | 1 | 1 | 1 | 1 | 1 | - |
| Ventilation level | - | - | - | - | 2 | 0 | 0 | 0 | - | - | - |
| Air movement in the construction | 2 | 1 | 1 | - | - | 0 | 1 | 0 | - | 0 | 0 |
| Air movement in room air | - | - | - | - | - | - | 2 | 1 | - | - | - |
| Surface temperature | 2 | 2 | 2 | - | - | - | - | - | - | - | - |
| Air temperature | - | 2 | - | - | - | - | - | - | - | - | - |

The appropriateness is evaluated according to following: 2 - suitable, recommended; 1 = less suitable (but can give an impression of the characteristic involved); 0 = not suitable; - = not applicable.

The measurement method poses certain requirements on temperature and pressure conditions throughout the construction project.
The method includes evaluation components which require competent and experienced measurement personnel.

## 2. Surface thermometer

| | |
|---|---|
| Instrument | Rapid thermometer. An electrical instrument with a thermal element or a resistance supplier |
| Measurement precision | ± 0.5 °C |
| Principle | The instrument (supplier) is placed in contact with the surface to be measured, whereby the temperature is measured at a specific point |
| Method | The heat resistance and insulation standard can be evaluated after measurement and charting of the surface temperature |
| Application area | Construction components, module edges, and connections. |

Advantages:
Measurement at certain specific points, where the real temperature of the surface is determined. Portions with decreased heat insulation capacity can be located. The method is relatively simple. The equipment is relatively inexpensive.

Limitations:
Time-consuming to locate insulation deficiencies and air leakages in an entire house.
The surface temperature field may be disturbed during the measurement through contact between the instrument and the surface to be measured.
The method requires certain temperature and pressure conditions. Normally, only severe insulation deficiencies will be discovered.
Competence and experience are required for evaluation of the results.

## 3. Infrared sensitive instrument

| | |
|---|---|
| Instrument | Radiation pyrometer |
| Measurement precision | ± 1 °C |
| Principle | Measures thermal radiation from the surface. Emissivity and temperature of the object determine the instrument reaction. |
| Method | The heat resistance and insulation standard can be evaluated after measuring the surface temperature. |
| Application area | Construction components, module edges, and connections. |

Advantages:
Measurements are performed at certain points where the surface temperature can be determined.

Measurement on a certain portion of the surface, more measuring points possible from one measuring position. No disturbing contact between the instrument and the surface to be measured. It is possible to measure surfaces which are difficult to reach. Surface portions with decreased insulation capability can be located.

Limitations:
Insufficient precision for absolute temperature determination. In certain cases unreliable. The radiation characteristics of the surface must be considered.
Requires certain temperature and pressure conditions. Competence and experience necessary for evaluating the results. Normally,only severe insulation deficiencies can be discovered.

B. Determination of heat resistance and k-value

1.

| | |
|---|---|
| Instrument | Devices for masuring heat flow and temperatures, and recording equipment |
| Measurement precisio.. | $\pm$ 10% |
| Principle | Measures the heat flow through the construction |
| Method | The heat resistance is determined by simultaneous measurements of temperature differences over and heat flow (one-minesionally) througn the construction under statiouary conditions |
| Application area | Construction components. |

Advantages:
The measurement provides values for the heat resistance ot k-value of the wall in certain surface portions. Relatively high level of measurement precision.

Limitations:
The measurement requires certain measurement conditions. Measurement values are obtained only for limited surface portions. Time-consuming to perform measurements in an entire building. Not suitable for use when the purpose is to discover insulation deficiencies.
The method requires competent and experienced personnel.
When supplemented with thermography, a chart of portions with decreased heat insulation capacity is obtained. Thermography can be used for correct placement of the measurement points.

2.

| | |
|---|---|
| Instrument | Mobile hot-box, equipment for temperature measurement and recording |
| Measurement precision | $\pm$ 10% |
| Principle | Measures the heat flow through a construction over a larger surface portion which may contain cold bridges. The |

| | |
|---|---|
| | open side of the hot-box is applied to the surface to be measured. The temperature of the box is adjusted so that it coincides with the outside temperature. The supplied effect passes through the test surface |
| Method | Simultaneous measurement of heat flow and surface temperatures at an equilibrium. (The method is not sufficiently developed for field use.) |
| Application area | Construction components, module edges. |

Advantages:
The measurement provides a quantitative value for the heat resistance or k-value of the wall over a specific surface portion which may contain so-called cold bridges. Relatively high level of measurement precision. Can be adjusted to various sizes.

Limitations:
The method requires specific measuring conditions. Time-consuming to perform measurements in an entire house. Not suitable for location of insulation defiencies and air leakages.
Competent and experienced measuring personnel is required.
Normally, the method is more suitable for laboratory use.
(Appropriate measurement locations can be defined in combination with thermography.)

## C. Testing and control of the air tightness of the building

### 1. The gas trace method

| | |
|---|---|
| Instrument | Gas analyzer |
| Measurement precision | - |
| Principle | The number of air changes per time unit in a facility (building) is determined by measuring the variations in trace gas concentration over time. |
| Method | The tightness standard and the energy losses are determined by identifying the ventilation level in the building under various conditions. (The method is not completely developed for field use). |
| Application area | Completed building (defined volumes) |

Advantages:
The measurement provides data concerning the ventilation level of the building under actual conditions. Continuous measurements over the course of a full year can provide values for annual ventilation losses in the building.

Limitations:
The method is time consuming, and competent measurement personnel is

required. Does not provide any information on leakage points. The measurement is a result of combined effects of the leakages of the building and the weather situation at the time of measurement. Air movements in the construction cannot be verified. Not suitable as a routine method for quality control of the air tightness of the building. Slow for tight buildings. Relatively complicated measuring equipment.
(Supplementation by means of thermography provides charting of leakage points.)

2. The pressure method

| | |
|---|---|
| Instrument | RPM-regulated fan with measurement tube for air flow. Micromanometer for pressure measurement. |
| Measurement precision | $\pm$ 6% |
| Principle | Determination of the air flow, Q, at a pressure drop of 50 Pa throughout the construction. The number of air changes is determined from the equation $n = \frac{Q}{V}$, where V stands for the volume of the building |
| Method | The tightness of the building is defined by determining the air flow through its enclosing surfaces |
| Application area | Completed building (defined, not too great volumes). |

Advantages:
Simple equipment for smaller volumes ( $< 700$ $m^3$). The method is rapid and unequivocal and provides a value for the air tightness of the building under added pressure.
Normally, the measurement is independent of the weather at the measuring occasion. The method is suitable for use e.g. in the quality control of air tightness of buildings, comparisons between buildings, and norm-determined requirements.

Limitations:
The measurement gives no information on real air leakage under operational conditions. The measurement does not locate the air leakages. Air movements in the construction cannot be detected. Larger equipment is required for greater volumes.
(Supplementation with thermography provides a charting of the leakage points.)

3. Air speed measurement

| | |
|---|---|
| Instrument | Air speed measurement device of the hot thread anemometer type |
| Measurement precision | $\pm$ 0.2 m/s |
| Principle | The hot thread anemometer uses the air cooling of a hot thread as an expression of the air speed. Measurement |

| | |
|---|---|
| | is performed at the surface of the construction where possible air movements will indicate an air leakage through the construction |
| Method | The tightness standard can be evaluated by measuring the air speed at the surface of the construction. |
| Application area | Joints, module edges, connections (e.g. at the eaves, joists, windows, etc.) |

Advantages:
The measurement provides values for the air speed at leakage points. Penetrating leakages in the construction can be discovered. The instrument is easy to handle. Leakage points can be located. Relatively inexpensive equipment.

Limitations:
Time consuming to locate air leakage in entire building. The measurement gives no information on the extent of the leakage. Air movements in the construction cannot be detected. Certain pressure difference over the construction is required (5 - 10 Pa). It may be difficult to evaluate the improvement actions on the sole basis of this measurement. Low reproducibility. Competent and experienced personnel needed to evaluate the result. (Valuable complement to thermography.)

## 4. Smoke gas test

| | |
|---|---|
| Instrument | Smoke gas pistol |
| Principle | By observing movements of smoke puffs, the air speed can be determined. In search for leakages in buildings, the smoke movements at the surface of the construction are visually observed. Movements of the smoke indicate air leakage through the construction. |
| Method | The tightness standard can be evaluated by observing the smoke movements. |
| Application area | Joints, module edges, connections, windows, etc. |

Advantages:
Penetration leaks in the construction can be discovered. An image of the air movements at the leakage point is obtained. The smoke gas provides information on the flow direction of the air and its approximate speed in the room. Can also provide information on leakage channels.

Limitations:
Time consuming to locate deficiency points. Does not provide values for air leak quantities. Depending on pressure drop through the construction. The smoke gas may be an irritant. Experience is required for evaluation of the results.

## 5. The soap bubble method

| | |
|---|---|
| Principle | Soapy water is applied to the surface of the construction, whereby bubbles |

| | |
|---|---|
| | indicate leakage points. |
| Method | By observing soap bubbles, one can evaluate the tightness standard of the building. |
| Application area | Module edges, joints, and connections. |

Advantages:
Penetrating leaks in the construction can be discovered. Indicates the leakage points. Good graphic indication.

Limitations:
Time consuming to locate leakage points. Requires pressure drop throughout the construction. Not suitable for application in complete buildings. Experience required for evaluating the result.

D. Inspection of insulation and tightness standard and workmanship by disassembling and visual inspection

| | |
|---|---|
| Instrument | Various tools and measures. |
| Principle | The construction is opened, and the workmanship of insulation and tightness is visually controlled. Measuring of insulation thicknesses, slits, and chinks. |
| Method | By opening certain portions and visual inspection, one can evaluate heat resistance as well as workmanship in insulation and tightness. Simultaneously, the drawings should be checked. |
| Application area | Construction components, joints, connections, etc. |

Advantages:
The method can directly show the absence or insufficiency of insulation material. Can be applied where there is a suspicion of damage or error.

Limitations:
Difficult to see the density of material in layers further in, to discover folds between material layers or against touching surfaces, etc. Air leakages can be difficult to discover with visual inspection. Possible deficiencies may be hidden by adjacent material. The method is destructive and can be both time-consuming and costly. Not suitable as routine method. (Can be used to supplement thermography for clarification of conditions. In certain cases, blatant errors and deficiencies can be discovered by simple methods, e.g. touching with the hand or observing dirt deposits on the surface.)

# 3. INFLUENTIAL PARAMETERS IN THERMOGRAPHY

## 3.1. The principle of the heat camera (IR camera)

In this context, IR technology is understood to mean an application where the infrared radiation (heat radiation emitted from an object is utilized for depicting this object and determining its temperature. At room temperature, the emitted radiation from a surface falls within the infrared radiation range (0.7 - 1,000 µm). The radiation from a surface depends not only on the temperature of the surface but also on its emitting and reflecting characteristics. An IR camera registers and depicts on an oscilloscope screen the heat radiation emitted or reflected from surface, doing this in the form of a black and white picture,a heat image. The technique of depicting and measuring the heat radiation is called thermography.

The characteristics of the IR camera are determined by its sensitivity range, thermal and optical resolution, the size of the image field, and the speed of searching. The modern infrared cameras, with a sensitivity range from 2.0 to 5.6 µm, are provided with an image searching system which allows measurement of the individual energy radiation from a great number of partial elements of a surface, and thus, the camera can construct a "radiation image" of the surface. The radiation image (heat image) appears on a screen of an oscilloscope (FIGURE 3). The heat image can be photographed with a regular camera, whereby a thermogram is obtained (FIGURE 3 b and 3 c).

Certain types of cameras can reproduce the temperature distribution both according to a grey scale (from black to white) and in a color scale.

In the black and white heat image (detail, FIGURE 3 b), portions with a darker grey tone represent surfaces with a lower temperature than portions in a lighter grey.

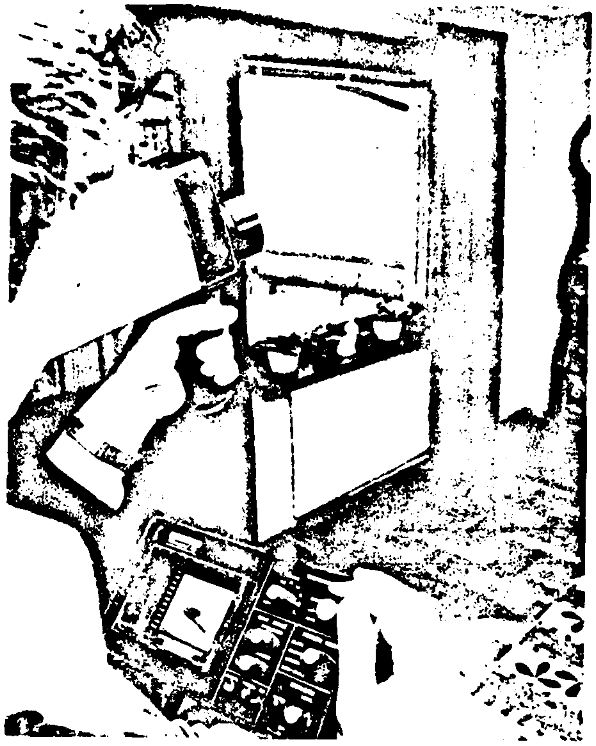
In a color thermogram (see FIGURE 33), each color tone represents a specific temperature interval. The temperature distribution over the surface is reproduced with good clarity.

Since the camera is continuously searching several images per second, each one containing 7,000 - 10,000 elements (depending on the camera type), the heat image obtained is relatively free of flickers and rich in detail. FIGURE 4 shows the principle of the IR camera. The surface to be measured is searched along a number of horizontal lines (which may be visible in some thermograms).

The size of the image element is determined by the size of the detector and the optics of the camera and is usually indicated by means of an angular resolution. For the camera types in use, this resolution is given as, for example, 3 millirad for 20° lens and approximately 1 millirad for a 10° lens. Thereby, the smallest element that can be discovered on a surface is a function of the distance between the object to be measured and the camera. The outlines in the heat image are more diffuse at great distances than at small distances. When the distances between object to be measured and the camera are great, one should therefore use a lens with a smaller angle.

Indium antimonide is used as a detector in most IR cameras. At -196°C (77K) it is sensitive within the wavelength range 0 - 5.6 µm. The lower

<u>**FIGURE 3**</u>: Photography with IR camera, AGA THV 750, and two different types of thermogram for the same surface measured.



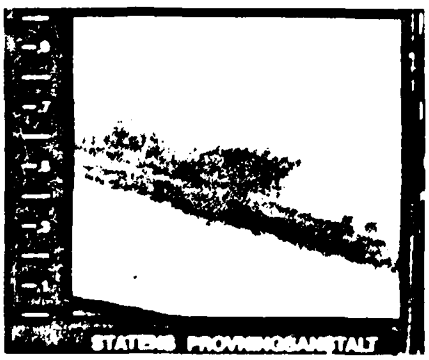
a)

a) Thermography with IR camera of a wall and roof portion. The heat image is reproduced on the screen of the oscilloscope.

b) Thermogram of a surface portion under the eaves according to a). No isoterms are entered (grey tone image). The measurement area of interest is indicated by a figure (in this picture, 2) in the top left corner of the thermogram.

c) Thermogram of the same surface portion as in b) with two isotherms entered (iso therm image).

b)




c)

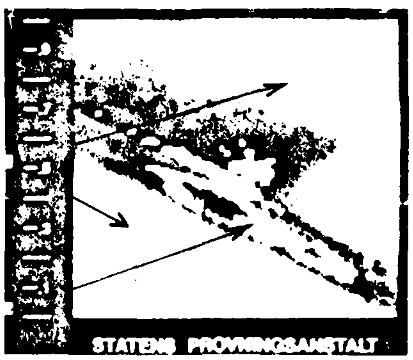
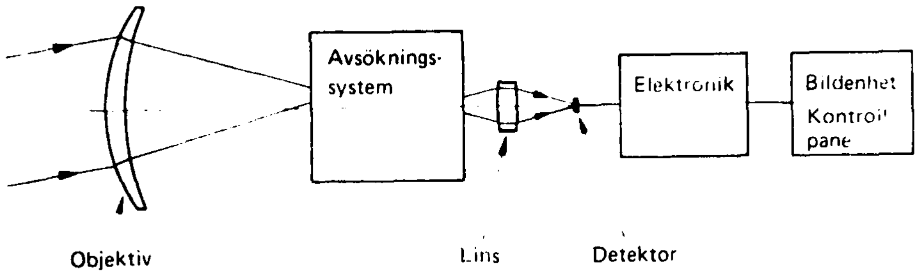


**FIGURE 4**: Illustration of the principle. The sequence of an IR camera.




Lens | Search system | Lens | Detector | Electronics | Image unit Control panel

wavelength limit of the camera is, however, determined by germanium lenses in the camera at 2 µm. The sensitivity range of the IR camera is shown in FIGURE 5.

The heat image (FIGURE 3 b), the degree of blackness is a function of the radiated energy and thereby the temperature of the various portions of the investigated surface.

The temperature range of the IR camera goes from approximately -20°C to +2,000°C. In the area of +30°C, the heat camera measures the temperature with a resolution of 0.2°C. The sensitivity decreases somewhat when lower temperatures are measured. This is also apparent from the calibration curve of the camera, FIGURE 6 b.

The character of a heat image differs from that of a photo image which represents the reflected radiation normally within the visible range. The heat image represents the emitted and reflected radiation within the sensitive range of the IR camera, 2.0 - 5.6 µm. A photo image represents shapes and outlines with great clarity. The heat image frequently has a coarser structure and a more diffuse representation of outlines. Primarily, this is due to the difference in resolution capacity but also to the fact that heat conduction in the surface will sometimes produce more gradual outlines.

In order to facilitate the measurement of temperature differences between different surface portions in the heat image, the IR camera has been provided with a so-called isotherm function. With the aid of this function, surface portions in the heat image which have the same temperature can be brought to luminescence - isotherms appear in the image, and one obtains an isotherm image (FIGURE 3 c). Isotherms can be placed at arbitrary temperatures and may cover variable temperature ranges within the image. Certain camera types have two isotherm functions. The isotherm differentials recorded, the so-called isotherm units, are transferred to corresponding differentials in centigrades (°C) if the real values have been inserted in the calibration function of the camera (Equation 3.1).

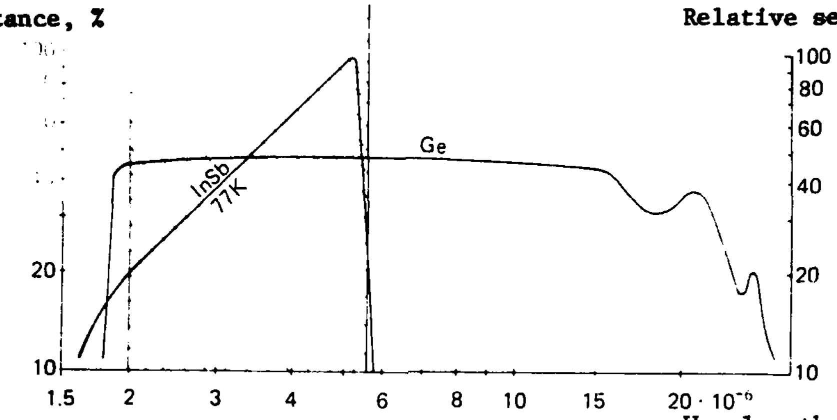
When determining temperatures of interest in the construction field, normally -20°C - +40°C, a specific calibration curve for the IR camera in use should be produced for the area of interest. See FIGURE 126.

As mentioned above, the IR camera only defines relative temperature differences within the image field. If it is desirable to determine the real

**FIGURE 5:** Spectral transmittance of germanium, Ge (thickness 2 mm), and relative detectability of indium antimonide, InSb. These materials limit the wavelength range within which the IR camera functions [13].

Transmittance, %

Relative sensitivity, %




Wavelength, m

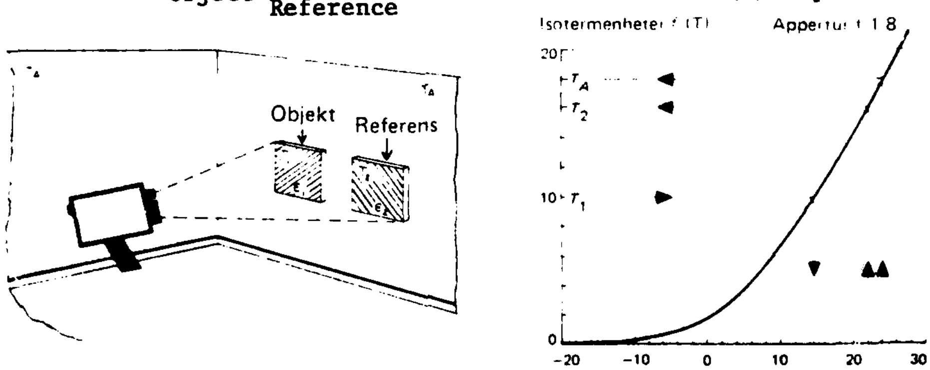
**FIGURE 6:** Determination of surface temperature of objects to be measured with IR camera.

a) Surface temperature measurement with IR camera.

b) Calibration curve with superimposed application example [12].

Object Reference

Isotherm units f (T) Aperture f/1.8




a) b) Surface temperature, °C

temperature of the surface, the following are required: real temperature at a reference point within the surface to be measured, the emission identification for the reference surface and the entire object to be measured, and, finally, the so-called temperature function and the calibration curves of the camera (FIGURE 6 b).

$$f(T_1) = \frac{\Delta I_{1,2}}{\epsilon_1} + \frac{\epsilon_2}{\epsilon_1} f(T_2) + (1 - \frac{\epsilon_2}{\epsilon_1}) f(T_A) \qquad (3.1)$$

| | |
|---|---|
| $T_1$ | Thermodynamic temperature at point 1 on the object to be measured, K (0°C = 273 K) |
| $T_2$ | Thermodynamic temperature at point 2 on the object to be measured, K |
| $T_A$ | Ambient temperature, K |
| $\underline{e}_1$ | Emittance at point 1 on the object to be measured |
| $\underline{e}_2$ | Emittance at point 2 on the object to be measured |
| $\Delta I_{1,2}$ | Difference in isotherm units between isotherm markings for points 1 and 2 |
| $f(T_1)$ | Functional value of $T_1$ according to the calibration curve |
| $f(T_2)$ | Functional value of $T_2$ according to the calibration curve |
| $f(T_A)$ | Functional value of $T_A$ according to the calibration curve. |

If the magnitudes to the right in Equation 3.1 are known, $f(T_1)$ can be calculated and $T_1$ can be determined.

When measuring homogeneous surfaces, $\underline{e}_1$ is frequently = $\underline{e}_2$. Thereby, the following is obtained:

$$f(T_1) = \frac{\Delta I_{1,2}}{\epsilon_1} + f(T_2) \qquad (3.2)$$

FIGURE 126 shows examples of temperature determination with heat camera in accordance with Equation 3.2. The precision of temperature measurement with heat camera is related to several factors and is primarily due to how well one can determine:

- the reflecting and emitting characteristics of the surfaces (see sections 3.2.2. and 3.2.3.),
- the real temperature ($T_2$) of the reference point,
- temperature of counter-radiating surfaces ($T_A$) and radiation from these surfaces (see section 3.2.3.),
- the calibration curve of the heat camera (see FIGURE t b),
- the isotherm difference $\Delta I$ from the isotherm image (see FIGURE 3 c),
- the optical and thermal resolution of the heat camera and the effect of the environment where the measurement is performed, as well as the effect of the distance between object and camera,
- the absorption of radiation in air on the way from measuring object to camera (see FIGURE 128).

The environment influences thermography with heat camera in two ways: the influence of the temperature on the measuring equipment, and the suppression of the thermal radiation in air.

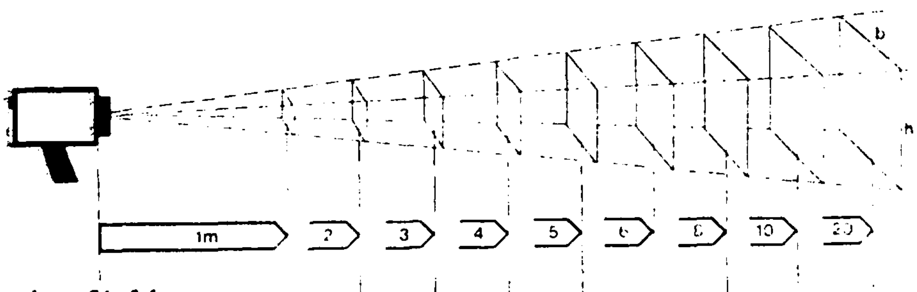
According to information from the camera manufacturer, the heat cameras in question can be used in an ambient temperature from -15°C to +55°C. This temperature interval has been selected primarily to ascertain the mechanical functioning (prism rotation, etc.) of the heat camera. The temperature effect on the sensitivity and stability of the measuring equipment is said to be negligible in the above-mentioned interval.

The suppression of thermal radiation in the atmosphere is mainly that absorption which occurs in the gas molecules and that absorption and scattering which takes place in particles. In pure air, the suppression is primarily related to the absorption in the molecules of water vapor and carbon dioxide. A typical curve for the correlation between radiation transmission in air (with a specific $CO_2$ content and humidity) and the distance between object and instrument is shown in FIGURE 128. When measuring at the distances common for building thermography indoors (1 - 6 m), the effect of the distance can be ignored. When measuring at distances greater than 10 - 20 m, a correction should be made for suppression in air. In this case, reference surface and measuring object should be located at the same distance from the instrument.

The distance also affects the camera recording of temperature radiation insofar that the optical resolution deteriorates when the distance increases, as has previously been pointed out. The optical sharpness of the measuring object in the heat image can be focused and adjusted b means of an adjustable lens.

The size of the image field captured by the camera is determined by the optical system of the camera. The size of the image field for different lenses is shown in FIGURE 7.

FIGURE 7: The measuring field of the IR camera at various distances between measuring object and camera, with 7° x 7° lens and with 20° x 20° lens (11).




**Measuring field, m**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 7° lens | b | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | h | [illegible] | [illegible] | 0.31 | [illegible] | 0.52 | [illegible] | [illegible] | [illegible] | [illegible] |
| 20° lens | b | [illegible] | [illegible] | 1.0 | [illegible] | 1.7 | [illegible] | [illegible] | [illegible] | [illegible] |
| | h | [illegible] | [illegible] | 0.92 | [illegible] | 1.5 | [illegible] | [illegible] | [illegible] | [illegible] |

When evaluating the errors of the components in the measuring change, the probable error for determination with heat camera of differences in surface temperature in the room temperature range can be estimated to ± 10% of the measured temperature difference, but not better than ± 0.5° C.

In our investigations, we have used mainly two types of heat cameras, manufactured by AB AGA, namely THV 680 and THV 750. The two models have approximately similar functions and characteristics. THV 750 is a small, portable equipment, suitable for field measurements. THV 680 is larger, and more suitable for laboratory use.

Tnermograms taken with the two camera types are generally of the same nature. There are certain differences in respect to scales and indications of real measuring area. In thermograms taken with THV 680, the grey tone scale (graduated in ten lines) is shown at the lower part of the thermogram (FIGURE 13 b). This grey tone scale is not shown on thermograms taken with THV 750, FIGURE 3. Here, the graduated scale is placed vertically to the left in the thermogram. Real measuring area for THV 680 is indicated by the location of the black slit on the left hand or right hand vertical scale. For THV 750, the measuring area is indicated by a figure at the top of the thermogram, see FIGURE 3 b.

The image frequency of THV 680 is 16 images per second and for THV 750 25 images per second.

## 3.2. Heat radiation

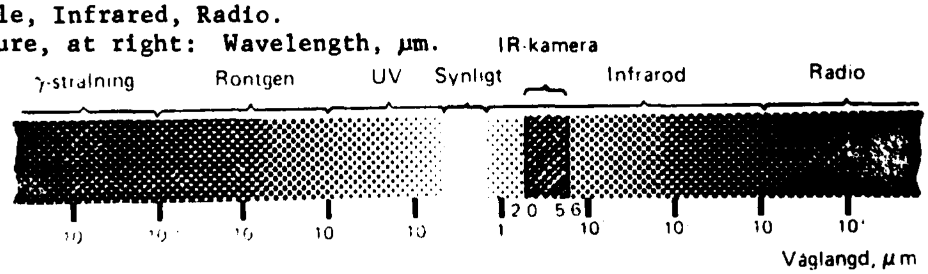
A basic condition for radiation measurement with an IR camera is that all bodies in our environment emit infrared radiation, which is a form of electromagnetic radiation. Alternately with the expression infrared radiation, such words as heat radiation, temperature radiation, or thermal radiation are used. The infrared radiation covers a wavelength range in the interval 0.7 - 1,000 µm, FIGURE 8. In the literature, one occasionally finds a subdivision of the IR range in "near IR" (NIR 0.7 - 3 um), "intermediate IR" (MIR 3 - 6 µm), "far IR" (FIR 6 - 15 µm), and "extreme IR" (XIR 15 - 1,000 µm).

In the 0.7 - 2 µm range, it is possible to use reflected sunlight or artificial light sources for detection of objects (active IR). Under certain conditions, this is used, e.g. in military surveillance and observations.

IR photography with infrared sensitive film, sensitive to radiation corresponding to temperatures above 400°C, cannot be used for depicting inherent emitted temperature radiation from surfaces with a temperature of about 20°C, i.e. that temperature range which is of interest in the construction field. IR photography with IR sensitive film is normally practiced in the 0.7 - 1.2 µm range. In thermography with heat camera, the IR radiation emitted by the object in the wavelength range 2.0 - 5.6 µm is of most interest, see FIGURE 8.

FIGURE 8: The electromagnetic spectrum (11).

Above figure: IR camera. Left to right: -radiation, X-ray, UV, Visible, Infrared, Radio.
Below figure, at right: Wavelength, µm.



### 3.2.1. "Black body" radiation

A black body is defined as absorbing all incoming radiation, independently of wavelength.

In a non-black body, a certain portion of the radiation towards the surface can be absorbed ($\underline{a}$), a certain portion transmitted ($\underline{r}$), and a certain portion reflected ($\underline{p}$). If the designations $\underline{a}$, $\underline{r}$, and $\underline{p}$ indicate the relative proportions, the correlation is

$$\underline{a} + \underline{r} + \underline{p} = 1. \qquad (3.3.)$$

The following applies to a black body:

$$\underline{a} = 1 \text{ and } \underline{r} = \underline{p} = 0.$$

An opaque (non-transparent surface absorbs or reflects all incoming radiation, i.e.,

$$\underline{a} + \underline{p} = 1 \text{ and } \underline{r} = 0. \qquad (3.4.)$$

The latter is most frequently the case for buildings. Windows and, for instance, PE foil would constitute some exceptions.

The radiation intensity of the thermal radiation from a black body is a function of both the wavelength ($\lambda$) and the temperature (T) and is described by means of Planck's distribution law:

$$E_{\lambda,T} = \frac{2\pi \cdot h \cdot c^2}{\lambda^5 \cdot (e^{hc/\lambda kT} - 1)} \ \mathrm{W\,m^3} \qquad (3.5.)$$

where

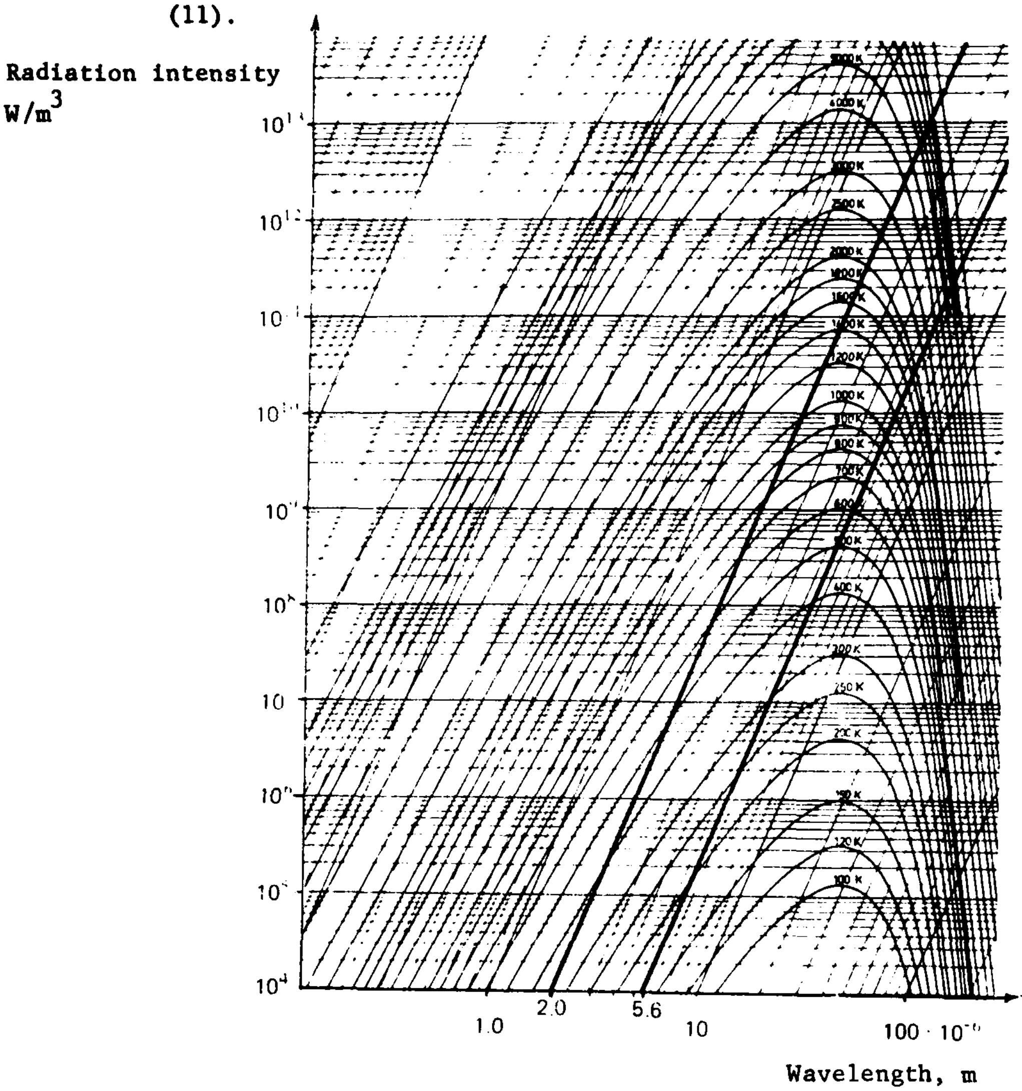
$E_{\lambda,T}$ = the spectral black body radiation at wavelength $\lambda$ (µm) and temperature T (K)
c = the speed of light, $3 \cdot 10^8$ m/s
h = Planck's constant $6.63 \cdot 10^{-34}\,\mathrm{Ws}^2$
k = Boltzmann's constant $1.38 \cdot 10^{-23}$ Ws/K
T = thermodynamic temperature, K.

The spectral radiation intensity is illustrated in the nomogram of FIGURE 9 for an oblique coordinate system where the radiation intensity corresponds to the y-axis and the wavelength corresponds to the x-axis, with the temperature as parameter (11).

The sensitivity range of the IR camera has been indicated in the nomogram.

The nomogram shows that the radiation intensity at 300 K (+27°C) is located mainly within the wavelength range 3 - 100 µm. The intensity increases with the temperature for all wavelengths. The increase is greater for shorter wavelengths, and the maximum of the radiation is dislocated towards shorter wavelengths at higher temperatures. The greater portion of the radiated energy will thereby fall within the sensitivity range of the camera, 2.0 - 5.6 µm. The wavelength at maximum spectral radiation intensity is described by Wien's dislocation law:

**FIGURE 9:** Radiation intensity for an absolute black body at various thermodynamic temperatures (100 - 5,000 K) as a function of the wavelength with the sensitivity range of the IR camera inserted (2.0 - 5.6 μm).
(11).




$$\lambda_{max} = \frac{2896}{T} \ (\mu m) \qquad (3.6.)$$

By integration of the spectral radiation intensity in the interval 0 - , one obtains the total radiation flow (Stefan-Boltzmann formula)

$$E = \sigma \cdot T^4 \ (W/m^2) \qquad (3.7.)$$

where

$\sigma$ = the Stefan-Boltzmann constant, $5.7 \cdot 10^{-8}$ $Ws/(m^2 \cdot K^4)$.

### 3.2.2. Emittance, e

The energy emitted from a real surface is always less than from a black surface. The curves for real surfaces will thus be located below that of the black surface, FIGURE 10.

The ratio between the energy emitted from a real surface and that from a black surface at a certain temperature is called the emittance (e) of the surface.

According to Kirchhoff's law,

$$\underline{e} = \underline{a} \tag{3.8.}$$

The emittance varies with the thermodynamic temperature of the surface, the wavelength of the radiation, and the radiation direction, i.e.

$$\underline{e} = f\ (T, \lambda, \phi).$$

In the temperature areas of interest in the construction technology, approximately -20°C to approximately +40°C, the temperature dependence of the e-value can be ignored.

If the e-value is independent of the wavelength, the surface is called grey, otherwise it is called colored.

FIGURE 11 shows the directional dependency of the emission of some metals (upper part of the figure) as well as for some non-metallic substances (lower part of the figure). The figure shows that the emission digit for non-metals is generally constant for angles between 0° and approximately 65°. Thereafter, the emittance decreases. For angles greater than approximately 70°, the e-value decreases relatively rapidly towards 0.

A so-called difuse surface is characterized by an e-value independent of the radiation direction. In the context of construction technology, the radiation of the surfaces can normally be considered diffuse. Exceptions are constituted by metals. However, compare with FIGURE 11 for wide entrance angles.

For metals, the emission digit depends on the direction in accordance with the upper part of FIGURE 11. Here the e-value is almost constant (0.04 - 0.06) between 0 and approximately 40 . The e-value increases with greater $\phi$.

If the surface is grey and diffuse, it would be possible to use one value for the emittance, which would simplifiy the evaluation of the radiation from the surface.

Tables give the e-value for various materials, both for certain wavelengths and as an average value within the entire wavelength range. Most surface materials used in buildings, with the exception of shiny metals,

have an e-value of 0.90 ± 0.05. The e-values suitable for the IR camera have previously been explored at the national testing institute (Statens provningsanstalt) and are reported in the appendix, Table 18 (12).

For shiny metals, the e-value is generally lower than 0.1. Thus, when measuring such surfaces, the major portion of the radiation will be due to reflected radiation from counter-radiating surfaces.

According to Equation 3.7., the emitted energy flow from a real surface will be

$$E = \epsilon \sigma \cdot T^4 \ (W/m^2) \qquad (3.9.)$$

### 3.2.3. Reflectance p

When radiation is measured with the IR camera, the heat radiation, $E_{tot}$, is recorded which is both emitted, $E_e$, and reflected, $E_r$, from the surface.

$$E_{tot} = E_e + E_r \qquad (3.10.)$$

According to previously stated correlation, the following applies:

$$\rho = 1 - \tau - a = 1 - \tau - \epsilon$$

For opaque surfaces $(\tau = 0)$, one obtains

$$\rho = 1 - \epsilon$$

In materials with e 0.9, the reflectance thus constitutes approximately 10% of the radiation falling on the surface. The reflection is usually diffused. Equation 3.10. gives

$$E_{tot} = \epsilon_1 \cdot \sigma T_1{}^4 + (1 - \epsilon_1) E_{in} \qquad (3.11.)$$

where

$E_{in}$ stands for the radiation coming onto the surface

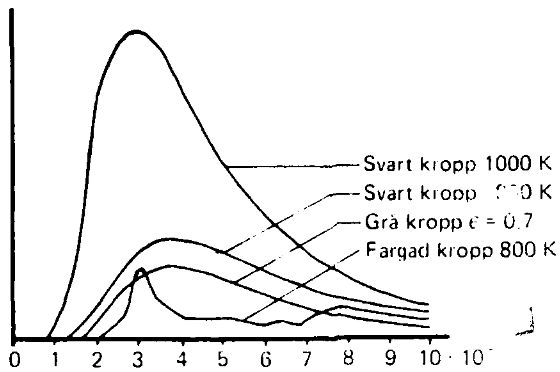
$$E_{in} \approx \epsilon_0 \cdot \sigma \cdot T_0{}^4$$

$e_o$ and $T_o$ are the radiation emmittance and thermodynamic temperature of the surface. Hereby, the contribution by reflection in this surface is ignored. $e_1$ is assumed to be independent of temperature. This gives

(3.12.)

**FIGURE 10:** The dependency of emittance on wavelength for black, grey, and colored bodies [4].

Radiation intensity W/m$^3$




Black body 1,000 K
Black body 800 K
Grey body e = 0.7
Colored body 800 K

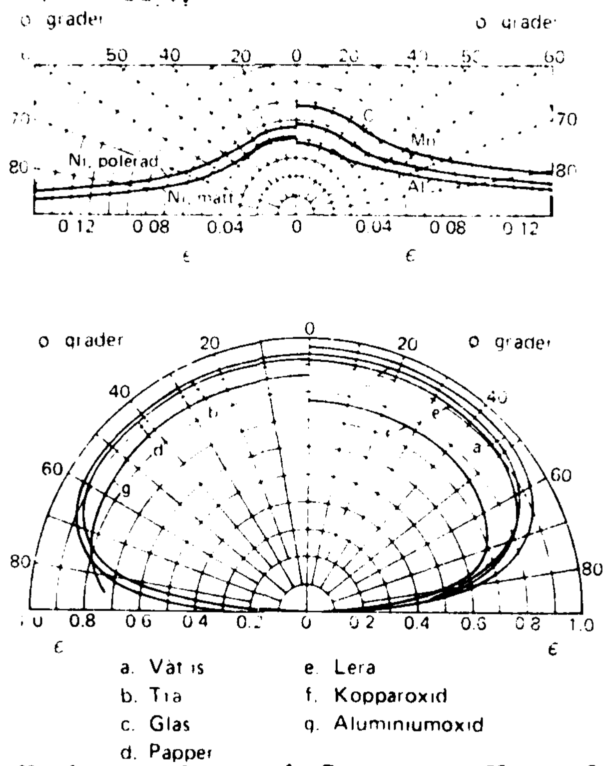
Wavelength, m

**FIGURE 11:** Emittance of various materials in different directions (according to Schmidt & Eckert). The temperature of the metallic surfaces was approx. +150° C and that of the non-metallic surfaces was between 0 and + 90°C.

ϕ degrees

(Ni, polished)
(Ni, matte)

ϕ degrees




a. Wet ice. b. Wood. c. Glass. d. Paper. e. Clay. f. Copper oxide. g. Aluminum oxide.

The difference in radiation from various partial surfaces is due to the temperature difference between the surfaces, on the condition that $\underline{e}_1$, $\underline{e}_0$, and $T_0$ are constant.

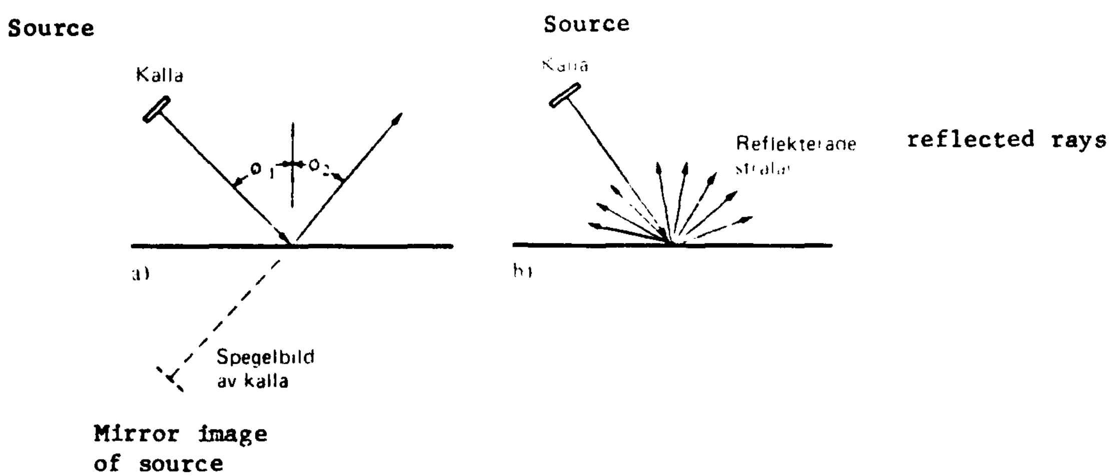
According to the correlation expressed in Equation 3.12., the radiation from a surface varies with the temperatures of both the object and the environment. Varying values for the reflectance (e.g. in shiny and parially oxidated metal surfaces ) can be difficult to interpret in the heat image.

In the case of shiny metal surfaces, radiation variations caused by reflections may produce apparent temperature differences in the heat image. If the surface is coarse, the reflection is diffuse, and if the surface is very smooth (fine grain), one obtains an optical reflection, FIGURE 12. Smooth surfaces may cause noticeable reflections in spite of high emittance (e.g. certain plastic materials).

When surfaces with a low emission figure are thermographed, the surface can be treated to increase the emittance. This can be done by painting the surface with a sufficiently thick layer of paint, e.g. a chalk or oil color with a high $\underline{e}$-value. See FIGURE 13 a and b.

In order to determine whether a radiation variation in the surface to be measured is caused by a reflection from a counter-radiating object, the surface in question can be studied from several measuring positions. Thereby, a reflex will change its position on the surface. A cooled or heated surface caused by a change of resistance in the construction will maintain its position on the surface independently of thermography position.

<u>FIGURE 12</u>:

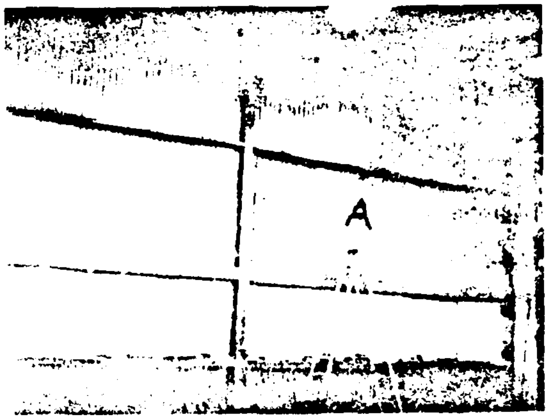



### <u>3.2.4. Transmittance, $\underline{r}$</u>

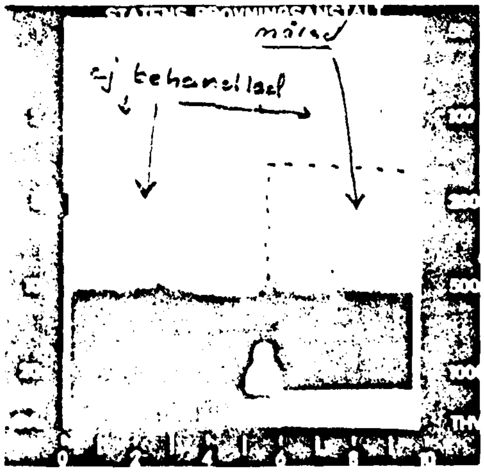
Specific measurement problems occur when the surface temperature is measured on glass surfaces. Ordinary glass materials are transparent in the near infrared range, FIGURE 14. Normal window glass is transparent for

FIGURE 13: Examples of how reflexes in the surface may affect the appearance of the thermogram.

a) Photography of exterior wall, taken from the inside. The wall covering consists partially of shiny corrugated steel sheets, partially of painted (matte, grey color) corrugated steel sheet (surface portion A).



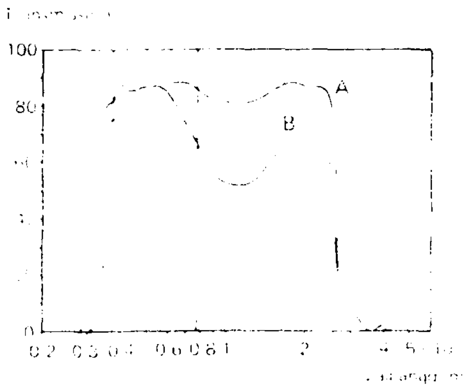

b) Thermogram of the same surface portion as represented in a), taken from a slightly different angle. Disturbing reflexes are shown in the thermogram at the upper parts of the wall, corresponding to the unpainted portions. In the lower left part of the thermogram, there is a light-colored area, corresponding to the upper body of a person. (In the figure: målad = painted; ej behandlad = not treated).



radiation within the wavelength range 0 - 5 µm. Thus, the glass allows radiation to pass through, even within the gre[illegible]er portion of the sensitivity range (2 - 5.6 µm) of the IR camera. If thermography of glass is performed in the usual manner, the thermogram will also contain the heat radiation transmitted through the glass. This measurement problem is appropriately

FIGURE 14: Transmission for ordinary glass materials (7).

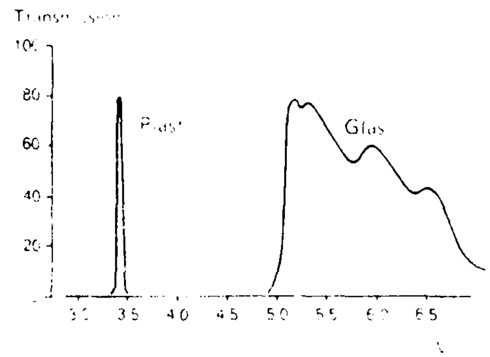
Transmission, %




Wavelength, m

FIGURE 15: Transmission for filter which can be used for measurements on thin plastic film (11).

Transmission, %




Wavelength, m

(Plast = plastic; Glas = glass)

solved by introducing a radiation filter on the camera, which will screen incoming radiation within the wavelength range 0 - 5 um. Such filter are available as accessories for the camera, thus giving it a different sensitivity and calibration curve.

Measuring on thin plastic film, e.g. PE foil, causes similar problems. However, the transmission wavelengths of thin plastic film are different from those of glass, which means that the radiation filter for plastic film is transparent over a small interval around 3.4 um, FIGURE 15.

## 3.3. Surface temperatures and heat resistance

### 3.3.1. Surface temperatures

For a one-dimensional and stationary heat flow, the surface temperature of a wall can be determined in a simplified manner through the following equations:

$$t_{vi} = t_i - \frac{m_i (t_i - t_u)}{m_i + m_u + M} \qquad (3.13.)$$

$$t_{vu} = t_u + \frac{m_u \cdot (t_i - t_u)}{m_i + m_u + M} \qquad (3.14.)$$

| | |
|---|---|
| $m_i$ | Heat transfer resistance at the warm surface of the wall, $m^2 \cdot K/W$ |
| $a_i (= \frac{1}{m_i})$ | Heat transfer coefficient at the warm surface of the wall, $W/(m^2 \cdot K)$ |
| $m_u$ | Heat transfer resistance at the cold surface of the wall, $m^2 \cdot K/W$ |
| $a_u (= \frac{1}{m_u})$ | Heat transfer coefficient at the cold surface of the wall, $W/(m^2 \cdot K)$ |
| M | Heat resistance of the wall, $m^2 \cdot K/W$ |
| $t_i$ | Air temperature on the warm side, °C |
| $t_{vi}$ | Surface temperature of the wall on the warm side, °C |
| $t_{vu}$ | Surface temperature of the wall on the cold side, °C |
| $t_u$ | Air temperature on the cold side, °C |

The heat resistance (M) for a construction component with various parallel layers perpendicular to the heat flow is determined according to

$$M = \Sigma \frac{d_i}{\lambda_i} \qquad (3.15.)$$

$d_i$ is the thickness of the material layer, in m

$\lambda i$ is the practically applicable heat conductivity of the material layer, expressed in W/(m · K).

Occasionally, the expression total heat resistance ($M_{tot}$) is used, which includes the heat transfer resistances at the surfaces

$$M_{tot} = m_i + m_u + M \qquad m^2 \cdot K/W \qquad (3.16.)$$

In the construction field, the so-called k-value is frequently used. This is a heat penetration coefficient defined as

$$k = \frac{1}{M_{tot}} \; W/(m^2 \cdot K).$$

Irregularities in the heat resistance in the construction result in a temperature variation along its surface. For the warm surface of the construction, the surface temperatures along wall 1 and 2 are determined according to Equation 3.13. with the heat resistances M and M , respectively, according to the following, see FIGURE 16:

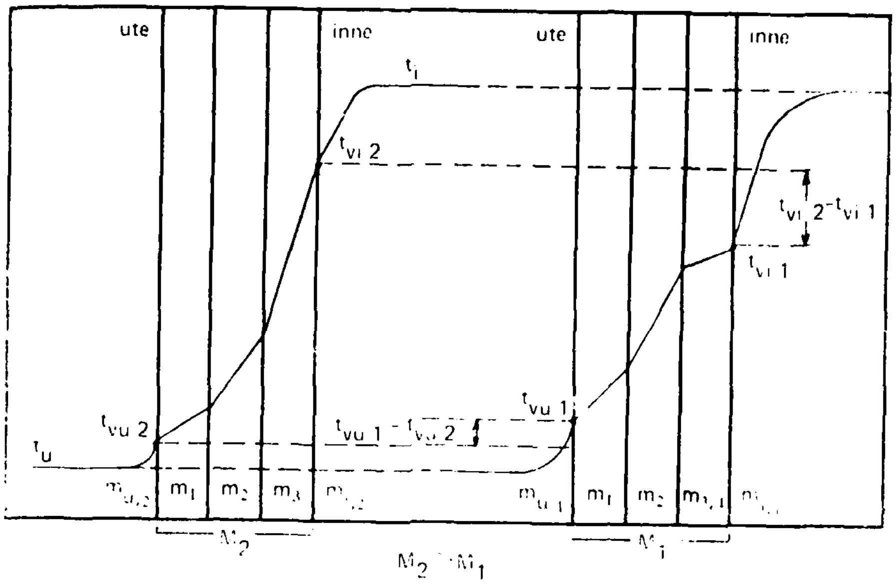
$$t_{vi_1} = t_i - \frac{m_{i.1}\,(t_i - t_u)}{m_{i.1} + m_{u.1} + M_1} = t_i - m_{i.1} \cdot k_1\,(t_i - t_u) \qquad (3.17)$$

$$t_{vi_2} = t_i - \frac{m_{i.2}\,(t_i - t_u)}{m_{i.2} + m_{u.2} + M_2} = t_i - m_{i.2} \cdot k_2\,(t_i - t_u) \qquad (3.18)$$

Antag att $m_{i.1} = m_{i.2}$, da erhalls

$$t_{vi_2} - t_{vi_1} = m_{i.1}\,(k_1 - k_2)\,(t_i - t_u) \qquad (3.19)$$

**FIGURE 16**: Temperature variations in a wall with the heat resistances $M_1$ and $M_2$ ($M_2 > M_1$)



### 3.3.2. Heat transfer resistance

When thermography is performed outdoors, i.e. on the cold side of the construction, the measurements can be disturbed by exterior climate factors (rain, sun, and wind). Normally, the heat transfer resistance is lesser on the outside of the wall than on its inside. Due to this, the temperature difference is lesser on the cold wall surface than on the warm surface if the heat resistance of the wall is changed. Thus, the resolution of the measuring result is not as good as

according to the following equation:

$$q = a_i (t_i - t_{vi}) \qquad (3.20.)$$

where q is the density of the heat flow, $W/m^2$.

In principle, a can thus be determined by measuring the temperature difference $t_i - t_{vi}$ and the density of the heatflow, q.

Heat is transferred to a wall surface from ambient air, mainly by convection and radiation from counter-radiating surfaces. Hereby, heat transfer by condensation and evaporation is disregarded.

Heat is transferred to the wall surface by convection according to the defined correlation

$$q_k = a_k (t_i - t_{vi}) \qquad (3.21)$$

$$\underline{a}_k = 1.85 \quad (t_i - t_{vi})^{0.32} \ (5) \qquad (3.22.)$$

FIGURE 17 shows how $\underline{a}_k$ varies with $T_i - T_{vi}$ · 0°C (t) corresponds to 273 K (T).

If the reflection between the surfaces is ignored and if $\underline{e}_0$ and $\underline{e}_n$ are independent of the temperature, the following is transferred by radiation

$$q_s = \Sigma\, \phi_n \epsilon_0 \cdot \epsilon_n C_s \left\{ \left(\frac{T_n}{100}\right)^4 - \left(\frac{T_0}{100}\right)^4 \right\} \qquad (3.23.)$$

where

$C_s$ = the radiation constant for black body, 5.7 $W/m^3K^4$

$\phi_n$ = the angle coefficient of the $n^{th}$ emitting surface

$T_n$ = the thermodynamic temperature, K, of the $n^{th}$ emitting surface

$\underline{e}_n$ = the emission figure of the $n^{th}$ emitting surface

$T_0$ = the thermodynamic temperature, K, of the receiving surface

$\underline{e}_0$ = the emission figure of the receiving surface.

The angle coefficient $\phi_n$ is defined as that part of the radiation which leaves the $n^{th}$ surface in all directions and reaches the receiving surface.

$\Sigma\, \phi_n$ varies between 0 and 1. When the enclosing surfaces combine to form a "half roon" as seen from the receiving surface, $\Sigma\phi_n = 1$.

In individual cases, consideration can be given to return reflection, e.g. in the case of two plane parallel walls (1 and 2) with such dimensions that the distance between them can be characterized as small. In radiation transfer at the inside surface of an exterior wall, it is occasionally assumed that the temperature of the interior walls is identical with the air temperature in the room ($T_n = T_i$).

If $T_0 - T_{vi}$, $\underline{e}_0 = \underline{e}_1$, and $\underline{e}_n = \underline{e}_2$, one obtains

$$q_s = \epsilon_{1\,2} \cdot C_s \left\{ \left(\frac{T_i}{100}\right)^4 - \left(\frac{T_{vi}}{100}\right)^4 \right\} \qquad (3.24.)$$

where

$\underline{e}_{1\,2}$ = the resulting emittance

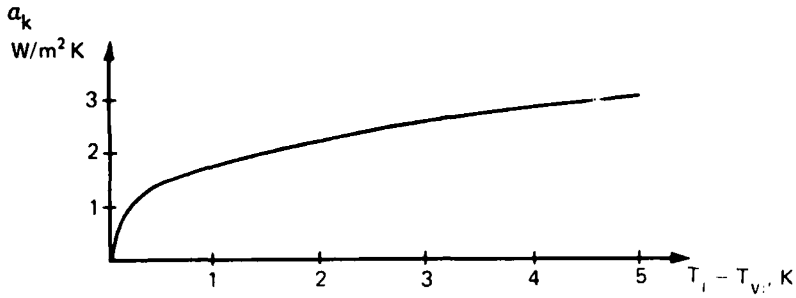
$$\frac{1}{\underline{e}_{1\,2}} = \frac{1}{\underline{e}_1} + \frac{1}{\underline{e}_2} - 1$$

For the purpose of comparison with $\underline{a}_k$, $\underline{a}_s$ can be simplified by serial development, whereby the following correlations are applied:

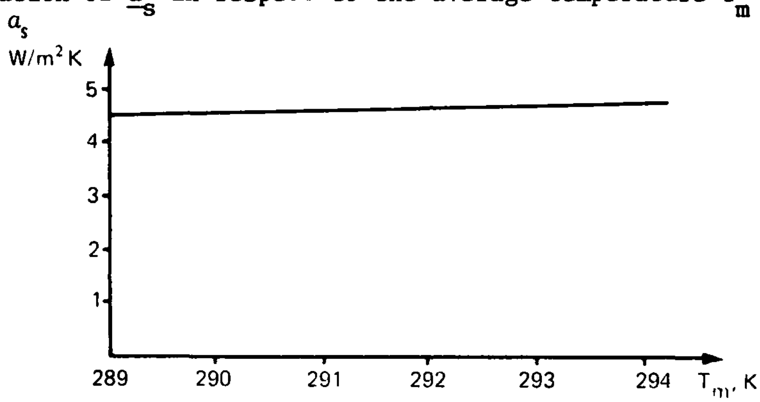
$$(a^4 - b^4) = (a - b)(a^3 + a^2b + ab^2 + b^3).$$

**FIGURE 17:** The variation of the heat transfer coefficient

a) Variation of $\underline{a}_k$ with respect to the temperature difference $T_i - T_{vi}$

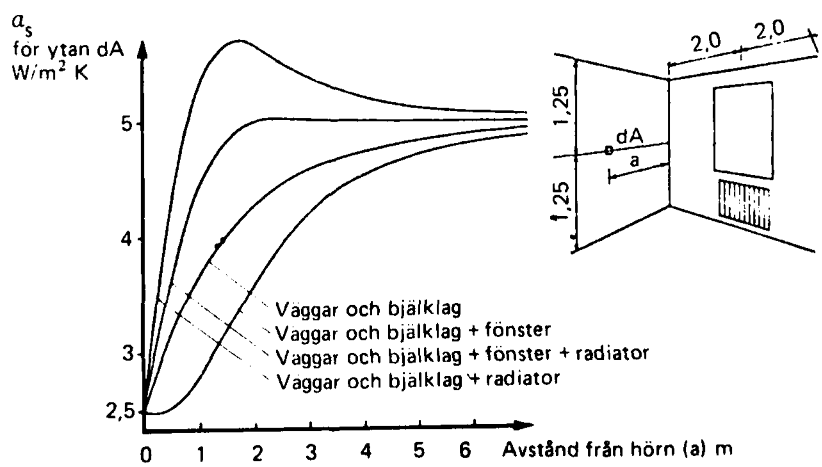



b) Variation of $\underline{a}_s$ in respect to the average temperature $T_m$




c) Example of variations of the heat transfer coefficient $\underline{a}_s$ at various distances from an exterior wall corner

$\underline{a}_s$ for the surface dA $W/m^2K$




Distance from corner (a), m

In the figure: Walls and joists; Walls and joists + windows; Walls and joists + windows + radiator; Walls and joists + radiator.

In buildings, the difference between $T_i$ and $T_{vi}$ is generally rather small in comparison with the absolute values. Considering this, one obtains

$$q_s = \epsilon_{12} \cdot C_s \frac{T_i - T_{vi}}{100} \cdot 4 \left(\frac{T_m}{100}\right)^3 \qquad (3.25.)$$

with the average temperature

$$T_m = \frac{T_i + T_{vi}}{2}$$

$$q = q_k + q_s \qquad (3.26.)$$

Equations 3.20., 3.21., 3.25., and 3.26. give

$$a_i = a_k + 0.04 \cdot \epsilon_{12} \cdot C_s \left(\frac{T_m}{100}\right)^3 \qquad (3.27.)$$

If $\underline{a}_s$ is defined as

$$a_s = 0.04 \cdot \epsilon_{12} \cdot C_s \left(\frac{T_m}{100}\right)^3 \qquad (3.28)$$

(3.29)

one obtains $\underline{a}_i = \underline{a}_k + \underline{a}_s$.

Thus, $\underline{a}_s$ can be determined if one knows the thermodynamic temperatures $T_i$ and $T_{vi}$ as well as $\underline{e}_{1\ 2}$.

FIGURE 17 b shows how $\underline{a}_s$ varies with $T_m$, whereby the following are assumed:

| | | |
|---|---|---|
| $\underline{e}_{1\ 2}$ | = 0.82 | |
| $C_s$ | = 5.7 | $W/m^2K^4$ |
| $T_i$ | = 294 | K ($t_i$ = 21°C) |
| $T_{vi}$ | = 284 - 294 | K ($t_{vi}$ = 11 - 21°C) |
| $T_m$ | = 289 - 294 | K ($t_m$ = 16 - 21°C). |

The value of $\underline{a}_s$ is also related to geometrical conditions and can vary considerably, e.g. at corners of exterior walls. FIGURE 17 c shows how $\underline{a}_s$ varies at various distances from the corner of the exterior wall.

The $\underline{a}_k$ value as well, is correlated to the geometry of a construction surface.

At the thermodynamic temperatures $T_i$ = 294 K and $T_{vi}$ = 292 K, the following values for $a_i$ are obtained from $\underline{a}_i$ at the center of an exterior wall:

$$\underline{a}_i = \underline{a}_k + \underline{a}_s = 4.7 + 2.3 = 7.0 \text{ W/(cm}^2 \cdot \text{K)}$$

or

$$m_i = 0.14 \ m^2 \ C/w.$$

If the heat transfer resistances $m_i$ and $m_u$ at the warm wall or the cold wall were known, as well as the temperatures $T_i$ and $T_{vi}$, a quantitive determination of the heat resistance M of the wall would be possible, see Equation 3.13.

### 3.3.3. Experimental investigation of heat transfer resistance

For the purpose of investigating the variation of the a-value over a wall surface under various environmental conditions, an exploratory investigation was performed at the National Testing Institute (Statens provningsanstalt). The studies were performed both in the laboratory and in the field.

#### Laboratory measurements

For the laboratory measurements, a test wall was used, the construction of which is shown in FIGURE 18.

The investigation was performed in a climate-controlled installation, provided with one climate room and one cold room, both with controlled temperatures and separated by means of the above-mentioned test wall.

The radiation conditions in the measurement room (the climate room) can generally be compared to those of a residential room, though with a modification of the placement of the heat source.

The radiation characteristics of the measurement room are defined as follows: walls and ceiling were painted with a light oil color, and the floor was covered with a grey linoleum product. The heat source of the measuring room was placed at the rear wall, behind a screen protecting against the radiation.

The a-value was determined from measured temperatures and heat flows, using equation 3.20. Heat flows through the wall were measured by means of a number of thermoelectric heat flow recorders of auxiliary wall type, placed on the warm surface at the measuring points 1 - 21 according to FIGURE 18.

The signals from the heat flow measurement devices were recorded by means of compensation recorders. The surface temperatures on the warm side of the heat flow recorder ($t_{vi}$) were measured with thermoelements at each one of the measuring points. The air temperature on the warm side ($t_i$) was measured 10 cm in front of the corresponding heat flow recorders by means of radiation protected thermoelements. This distance was selected after exploratory tests of the expansion of the air temperature decreases from the wall surface. The temperature difference $t_1$ to $t_{vi}$ was measured with (ill.) coupled thermoelements.

The measurements were performed with three variations:

1. Normal situation (no sources of disturbance)

2. Disturbance sources in the form of fans directed towards the test wall in order to produce high convective a-values. The fans were placed under the ceiling surface, directed towards the upper part of the test wall, FIGURE 18. The air speed along the wall surface varied, due to this placement, between approximately 0.2 and 1 m/s.

FIGURE 18: Construction of exterior wall (type bolted wall No. 1) used for determination of a-value distribution over the surface. The placement of the measuring points is marked 1 - 21 [12].

To the right of the drawing, top to bottom:

100 + 50 mm mineral wool panels, bulk density 50 $kg/m^3$
Vapor barrier of plastic foil
3/4" tongue and groove
13 mm gypsum panel
Fan
5 mm asbestos cement panel ( eternite )
8 mm air space
2" x 6" wood bolt
3.2 mm panel, asbestos-cellulose-cement (Internit)
120 mm rockwool panel, bulk density 50 $kg/m^3$
2" x 4" radiator support
Vapor barrier, plastic foil
13 mm gypsum panel
10 mm particle board
40 mm rockwool panel

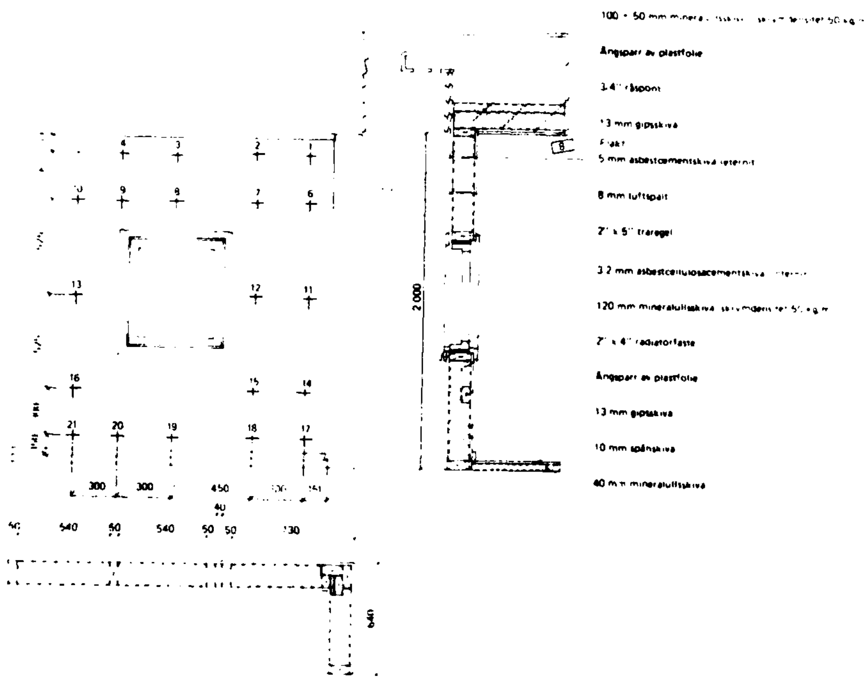
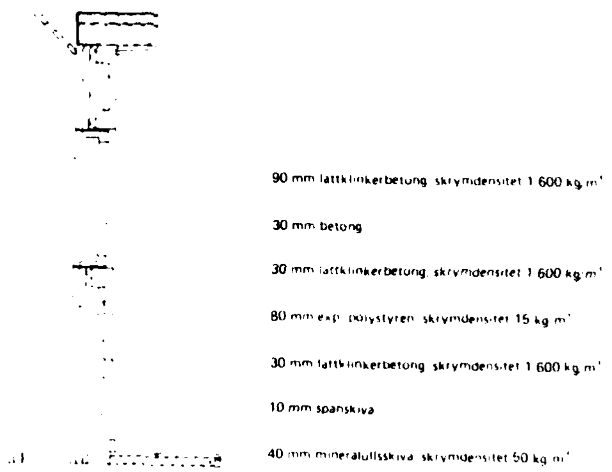


**FIGURE 19:** Determination of the a-value variation on an exterior wall.

a) Construction of exterior wall, on which the measurement was performed to determine the variation of the a-value along the wall surface [12].




To the right:
90 mm light clinker concrete bulk density 1,600 kg/m$^3$

30 mm concrete

30 mm light clinker concrete bulk density 1,600 kg/m$^3$

80 mm expanded polystyrene bulk density 15 kg/m$^3$

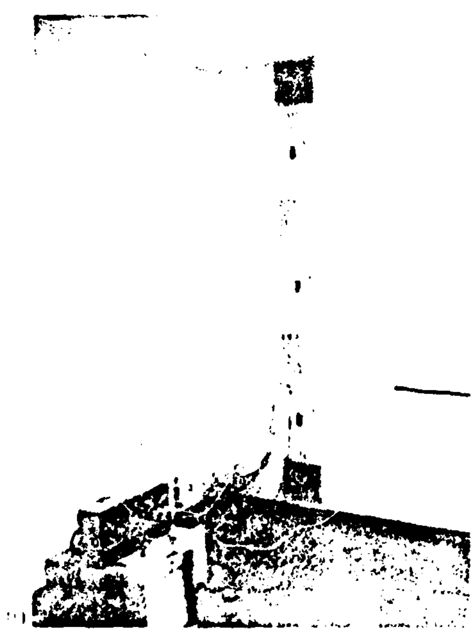
30 mm light clinker concrete bulk density 1,600 kg/m$^3$

10 mm particle board

40 mm rockwool panel, bulk density 50 kg/m$^3$

b) Measuring equipment for determination of the a-value.

c) Thermogram of the upper part of the exterior wall, to the left of the window.



c)

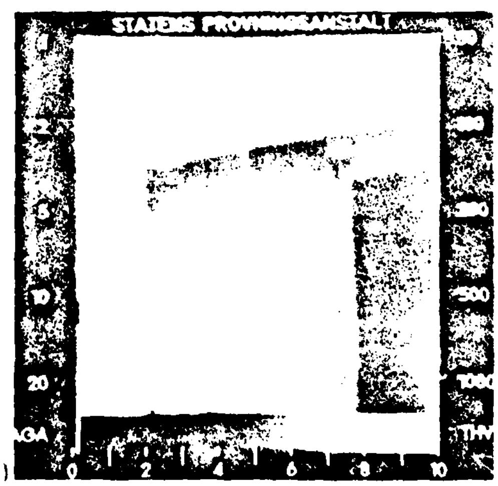


**TABLE 2:** Heat transfer coefficient (a-value) of a wall surface, measuring cases 1 - 3.

Column headings, left to right: Measuring point / 1, 2, and 3: q - W/$m^2$; $t_1 - t_{vi}$ -- °C; a - W/($m^2$ · K).

Last line of table: Average value: (1) 7.8; (2) 11.3; (3) 17.6.

Below table:

Average value for the surface temperature, $t_{vi}$ in case 1: 17.9°C; in case 2, 21.8°C; in case 3, 21.4°C.

| Mät-pkt | 1<br>q<br>W/$m^2$ | <br>$t_i$-$t_{vi}$<br>°C | <br>a<br>W/($m^2$·K) | 2<br>q<br>W/$m^2$ | <br>$t_i$-$t_{vi}$<br>°C | <br>a<br>W/($m^2$·K) | 3<br>q<br>W/$m^2$ | <br>$t_i$-$t_{vi}$<br>°C | <br>a<br>W/($m^2$·K) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 11,3 | 1,6 | 7,1 | 11,9 | 1,0 | 11,9 | 11,8 | 1,0 | 12,1 |
| 2 | 10,2 | 1,4 | 7,3 | 11,2 | 0,8 | 14,0 | 9,7 | 0,8 | 12,1 |
| 3 | 9,1 | 1,3 | 7,0 | 9,8 | 0,8 | 12,3 | 9,2 | 0,7 | 13,1 |
| 4 | 16,9 | 2,6 | 6,5 | 19,2 | 1,8 | 10,7 | 17,7 | 2,2 | 8,0 |
| 5 | 8,8 | 1,3 | 6,8 | 9,5 | 0,9 | 10,6 | 9,5 | 0,9 | 10,6 |
| 6 | 9,5 | 1,6 | 5,9 | 10,0 | 0,7 | 14,3 | 9,7 | 0,5 | 19,4 |
| 7 | 9,0 | 1,4 | 6,4 | 10,0 | 0,6 | 16,7 | 9,7 | 0,4 | 24,3 |
| 8 | 10,1 | 1,4 | 7,2 | 10,8 | 0,8 | 13,5 | 10,0 | 0,3 | 33,3 |
| 9 | 17,0 | 2,4 | 7,1 | 20,3 | 1,7 | 11,9 | 17,0 | 1,8 | 9,4 |
| 10 | 9,2 | 1,1 | 8,4 | 9,1 | 0,6 | 15,2 | 8,7 | 0,5 | 17,4 |
| 11 | 12,2 | 1,9 | 6,4 | 13,0 | 1,5 | 8,7 | 12,1 | 0,5 | 17,3 |
| 12 | 10,1 | 1,4 | 7,2 | 11,5 | 0,9 | 12,8 | 10,2 | 0,7 | 14,6 |
| 13 | 9,1 | 1,2 | 7,6 | 10,4 | 0,8 | 13,0 | 9,3 | 0,7 | 13,3 |
| 14 | 10,4 | 1,3 | 8,0 | 11,1 | 1,5 | 7,4 | 11,1 | 0,5 | 22,2 |
| 15 | 9,4 | 1,1 | 8,5 | 10,5 | 1,2 | 8,8 | 9,8 | 0,4 | 24,5 |
| 16 | 8,6 | 1,0 | 8,6 | 9,4 | 0,8 | 11,8 | 8,2 | 0,3 | 27,3 |
| 17 | 13,9 | 1,9 | 7,3 | 15,5 | 2,0 | 7,8 | 14,7 | 0,9 | 16,3 |
| 18 | 10,3 | 1,0 | 10,3 | 11,5 | 1,4 | 8,2 | 11,3 | 0,5 | 22,6 |
| 19 | 10,2 | 1,0 | 10,2 | 11,4 | 1,2 | 9,5 | 10,2 | 0,6 | 17,0 |
| 20 | 18,0 | 2,1 | 8,6 | 19,9 | 2,4 | 8,3 | 19,3 | 1,4 | 13,8 |
| 21 | 14,2 | 1,4 | 10,1 | 15,4 | 1,5 | 10,3 | 14,2 | 0,7 | 20,3 |
| Medelvärde: | | | 7,8 | | | 11,3 | | | 17,6 |

Medelvärdet av yttemperaturen, $t_{vi}$, var vid mätfall 1; 17,9 °C; mätfall 2; 21,8 °C; mätfall 3; 21,4 °C.

3. Disturbance source in the form of a radiation point (heat lamp 250 W), located approximately 2 m from the warm wall surface and centrally in the climate room. The lamp was directed perpendicularly towards the surface.

The air temperature in the cold room was adjusted to -20°C and was maintained constant for all three measurings. The air temperature on the warm side varied between 21 and 23° C for the various measurements. The measurements were performed under constant conditions and were repeated three times. The results obtained from the measurements are shown in Table 2. The measurement precision of the obtained values was estimated at ± 8%.

The results show that a varied between approximately 6 and 10 $W/(m^2 \cdot K)$ in case 1, between approximately 7 and 17 in case 2, and between approximately 8 and 33 in case 3.

In each measuring case, the variation of the a-value was relatively small along a horizontal line at a specific height above the floor, 6.4 - 8.4 $W/(m^2 \cdot K)$. Vertically, the variation is slightly greater, approximately 7 - 10. The extreme values were obtained along the edges of the wall, with the highest values at the bottom of the wall. In the normal case, the a-value seems to vary symmetrically, and relatively constantly in a horizontal direction, with exception of surface portions close to corners. Vertically, there is a certain variation. The higher value at the bottom of the wall is probably related to the placement of the heat source in the test room and with the air flow conditions along the test wall.

In measuring case 2, the a-value increased due to increased air speed at the wall surface. The disturbance thus introduced was not symmetrically distributed over the wall surface, which caused a somewhat uneven effect on the a-value. The a-value increased most at the upper part of the wall, where the fans were placed. Such an uneven disturbance of the air flow along the inside of the wall has local effects on the temperature of the wall surface. A constant increase of the a-value along the entire surface has an equalizing effect on the distribution of the surface temperature of the wall.

In measurement case 3, the disturbance was constituted by a heat lamp, centrally placed at a certain distance from the wall surface The influence of the radiation source on the a-value is relatively evenly distributed - with exception of the values at measuring points 4 and 9 - over the entire exposed surface, with a slightly higher effect on the central parts of the wall. The a-value increased noticeably, and the temperature difference between the wall surface and the air temperature in the room decreased. Such variations of the a-value may have a local effect on the surface temperature, so that those differences in surface temperature are decreased which correspond to the variation of the heat resistance.

## Field measurement

The measurement of the a-value variation along the surface of an exterior wall was performed in an apartment in a multiple dwelling. The construction of the outside wall is shown in FIGURE 19 a. The measurements were performed at four measuring points on the wall surface, along a vertical line and at the levels 20, 90, 165, 235 cm above the floor. The ceiling in the apartment was 250 cm. The exterior wall was provided with window and radiator. FIGURE 19 b and c shows photographs of the outside wall and the equipment. Counter-

radiating surfaces consisted of walls, floor, and ceilings towards heated areas. The apartment was not furnished or inhabited at the measuring time. Temperatures and heat flows were measured in ways corresponding to the laboratory measurements. However, the air temperature was measured at the geometrical center of the room, and consequently, $t_{im}$ is an average value for the variations of air temperature in the room. The $\underline{a}_i$-value was determined according to the previously defined correlations (Equation 3.20) but based on this temperature.

Repeated measurements were performed during a prolonged period of time (approximately one month). The average for the $\underline{a}_i$-value at the measuring points 20, 90, 165, and 235 cm above the floor was 5.4, 6.6, 6.2, and 5.0 $W/(m^2 \cdot K)$, respectively.

The results show that the variation of the $\underline{a}$-value is relatively small at the center of the wall. The lowest values were obtained at the floor and ceiling angles. Compare also the thermogram of the surface portion in question, FIGURE 19 c.

### 3.3.4. Sources of disturbance in thermography

Under normal conditions, it is considered that there is little danger of confusing temperature variations caused by insulation deficiencies with those related to the natural variation of the $\underline{a}$-value along the warm surface of a construction, (these can be distinguished) in the interpretation of the thermogram.

The temperature changes related to the variation of the $\underline{a}$-value are usually gradual and symmetrically distributed over the surface. Such variations are naturally located at ceiling and floor angles and at wall corners.

Temperature changes related to air leakage or insulation deficiencies are usually more obvious, with sharp outlines of a characteristic shape. The temperature image usually has a non-symmetrical shape.

Previously produced comparative thermograms can provide valuable information in thermography and interpretation of thermograms.

The most common sources of disturbance that are encountered in practical applications of thermography are: influence of sun on the surface to be thermographed (inward radiation through windows), hot radiators with conduits, lamps lit and directed to and/or placed close to the measurement surface, air flows (e.g. from air intakes) directed towards the surface, and the effect of moisture deposits on the surface.

Thermography should not be performed on surfaces in direct sunlight. If there is a risk for sun effect, the windows are to be covered (blinds to be closed).

A warm radiator appears as a distinguishable light surface on the thermogram. Surface temperatures on the wall surface close to a heated radiator are raised and may conceal potential deficiencies.

In order to prevent distrubing influence of warm radiators as much as possible, these can be turned off shortly before the measurement. However, this must not lower the air temperature of the room so much that the distribution of surface temperature over the construction surfaces is affected. Electrical heaters have relatively low inertia and cool off relatively fast after disconnection (20 - 30 minutes).

Prior to thermography of surface portions behind a radiator, the radiator must be removed so that the wall surface can be exposed to the IR camera. It

must be considered that such surface portions may be affected by stored heat in the construction, even for some time after the removal of the radiator.

Illumination lamps placed close to a wall surface are to be extinguished at the measuring occasion.

No disturbing air flows (e.g. open windows, open vents, fans directed towards the measuring surface) should be allowed during thermography, since they may affect the surfaces to be observed by means of thermography.

Some surfaces may be moist, e.g. due to surface condensation; this affects the heat transfer at the surface as well as the surface temperature in a noticeable manner. When there is moisture on the surface, there is normally an evaporation process which consumes heat, and the surface can therefore be cooled by several degrees. There is a risk of surface condensation if there are strong cold bridges and insulation deficiencies. FIGURE 127 shows a diagram of the saturation temperature at various air temperatures and relative humidity of the air in the room. When thermography is performed, the area is to be carefully observed so that possible surface moisture will be discovered.

Normally, significant disturbances of the types indicated here can be discovered and eliminated prior to the measurement.

If, at the time of performing the thermography observation, it is impossible to screen the measuring surfaces from disturbing factors, this is to be taken into consideration when the results are interpreted and evaluated. The real measurement conditions are to be carefully noted for each measuring occasion.

## 3.4. Surface temperature and air leakage

Inadequacies in the air tightness of a building as a result of small openings in the construction can be discovered by means of measuring the surface temperature. If there is a negative pressure in the building uder study, air flows into the room through leaks in the building. Cold outside air flowing through small openings in a wall usually lower the temperature of adjacent wall portions. The result is that cooled surface portions with a characteristic shape occur on the interior wall surface. These cooled surface portions can be detected by means of thermography. Air movements along the wall surface can be measured with air speed recorders. If there is a positive pressure in the building under study, the warm air of the rooms will leak out through the permeable spots in the wall and cause locally warm surface portions in the vicinity of the leakages.

The extent of the air leakage is dependent on both the leakages and the pressure difference throughout the construction.

### 3.4.1. Pressure conditions in a building

The most important causes of pressure differences throughout a construction portion of a building are

- wind conditions around the building;
- the effects of the ventilation system;
- temperature difference between indoor and outside air (thermal pressure difference).

The real pressure conditions in a building are usually due to a combination of these factors.

The resulting pressure gradient throughout the various building components can be exemplified by FIGURE 20. The irregular effect of the wind on a building will result in relatively variable and complicated pressure conditions to be considered in the practice.

In a free wind flow, Bernoulli's law applies:

$$\frac{\rho v^2}{2} + p = \text{constant} \qquad (3.30.)$$

where

$\rho$ = density of the air, kg/m$^3$
v = velocity of the wind, m/s
p = static pressure, Pa

and where

$$\frac{\rho v^2}{2}$$

constitutes the dynamic and p the static pressure. The total of these pressures constitute the total pressure.

When there is a wind load on a surface, the dynamic pressure is changed into a static pressure against the surface. The magnitude of the static pressure is determined by e.g. the shape and slope of the surface in relation to the direction of the wind.

That portion of the dynamic pressure which is changed to static pressure on the surface ($p_{stat}$) is determined by a so-called form factor

$$C = \frac{p_{stat}}{\frac{\rho v^2}{2}} \qquad (3.31.)$$

If $\rho$ is assumed to be 1.23 kg/m$^3$ (density of the air at +15°C), the following local pressure in the wind flow is obtained:

$$p_{stat} = C \cdot \frac{\rho v^2}{2} = C \cdot \frac{v^2}{1.63} \text{ Pa} \qquad (3.32.)$$

If the entire dynamic pressure is changed into static pressure, C = 1. FIGURE 21 shows an example of form factor distribution for a building with different wind directions (2)

Thus, the wind causes an indoor negative pressure on the wind side and an indoor positive pressure on the leeward side The indoors air pressure depends on wind conditions, existing leakages in the building, and the distribution of these in relation to the wind direction. If the leakages in the building are evenly distributed, the indoors pressure may vary by $\pm$ 0.2 $p_{stat}$.

FIGURE 20: Distribution of resulting pressure on surfaces enclosing a building, due to the wind effect, ventilation, and temperature difference indoors/outdoors.

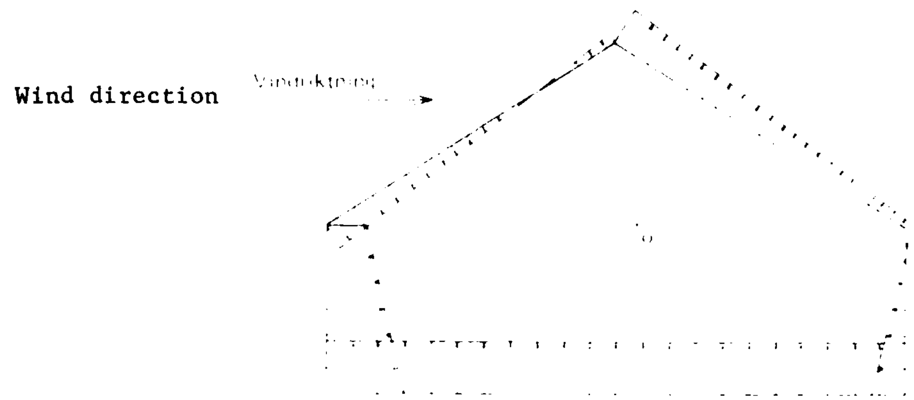
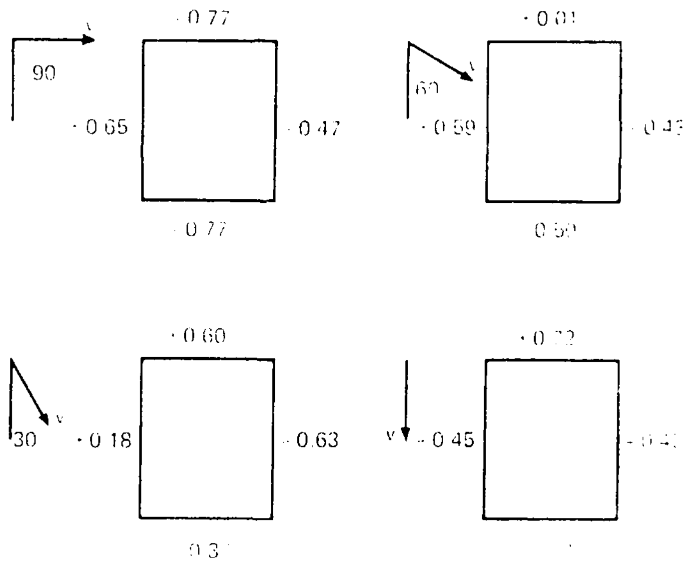



FIGURE 21: Distribution of the form factor (C) for different wind directions and wind velocity (v) against a building (2).




If there is a greater proportion of leakages on the windward side, the indoor pressure increases somewhat. In the reverse case, with more leakages on the leeward side, the indoors pressure decreases (3).

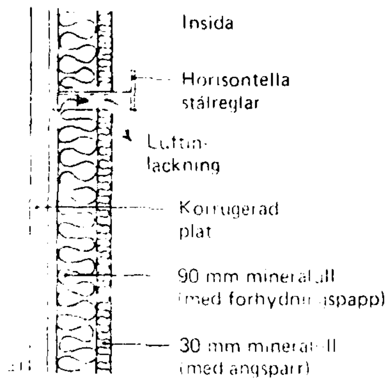
The wind conditions can vary significantly over time and at locations relatively close to each other. Other variations can definitely affect the measuring results of thermography. Examples are shown in FIGURE 22. There may also be local variations due to the design of the (number and placement of) buildings in the area as well as surrounding terrain.

FIGURE 22: Wind effect on temperature distribution on the inside of the wall with leakages in the construction. The thermograms are taken in the same measurement area, 2.

Measuring conditions:

| | |
|---|---|
| Cloud cover | cloudy |
| Air temperature outdoors | -1°C |
| Air temperature indoors | +19°C |
| Wind conditions | 1 - 4 m/s (against the facade) |
| $P_i - P_u$ | - 10 Pa to 0 Pa (fluctuating with wind pressure) |

a) Outside wall with steel construction




Top to bottom:

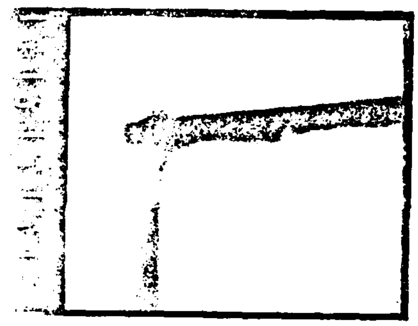
Horizontal steel bolts

Air leakage, in

Corrugated sheet metal

90 mm mineral wool
(with sheathing paper)

30 mm mineral wool
(with vapor barrier


b)

b) 0 minutes. The horizontal bolt cooled. Minor signs of air leakage appear.

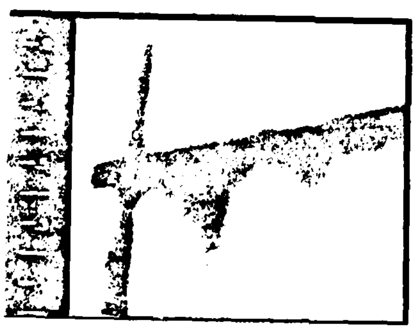
c) After 1 minute. Dark portions appear on the wall surface below the steel bolt.

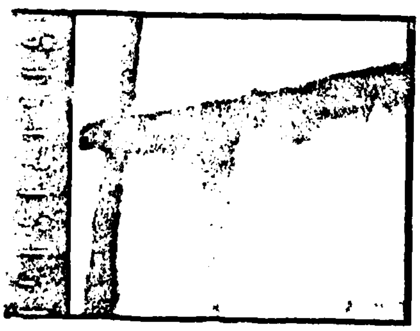
d) After 2 minutes. Darker portions larger than in picture c).

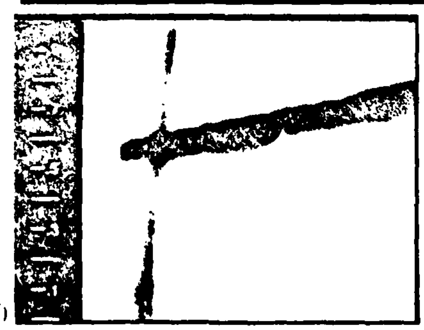
e) After 3 minutes. The dark portions below the bolt are still visible.

f) After 4 minuts. The thermogram resembles that in picture b).

(e and f on next page)


d)


e)


f)

Experiments have shown that the pressure difference over a building facade exposed to an average wind force of approximately 5 m/s will be approximately 10 Pa.

Mechanical ventilation causes a constant indoor negative or positive pressure (depending on the direction of the ventilation). Measurements in conjunction with our investigations have shown that in small houses, negative pressure caused by mechanical outward suction (kitchen fan) is normally between 5 and 10 Pa. When the ventilation air is mechanically sucked out, e.g. in multiple dwellings, such as apartment houses, the negative pressure is usually somewhat greater, 10 - 50 Pa. In the case of so-called balanced ventilation (mechanically regulated in/out air), an adjustment is normally made so that there is a minor negative pressure indoors (3 - 5 Pa).

The pressure difference caused by temperature differences, so-called chimney effect (density differences in air of differing temperatures) causes a negative pressure in the lower part of the building and a positive pressure in the upper parts. At a certain level, there is a neutral zone where the pressure indoors and outdoors is the same, FIGURE 23. This pressure difference can be described by the correlation

$$\Delta p = g \cdot \rho_u \cdot h \, (1 - \frac{T_u}{T_i}) \text{ Pa}$$

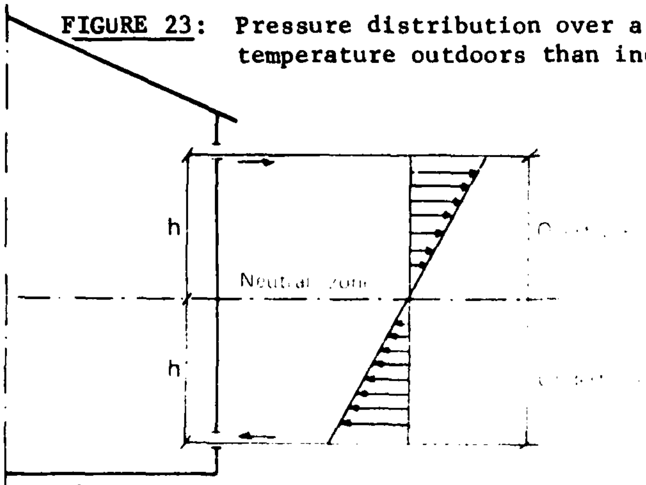
| | |
|---|---|
| $\Delta p$ | Air pressure difference throughout the construction, Pa |
| $g$ | 9.81 $m/s^2$ |
| $\rho_u$ | Air density, $kg/m^3$ |
| $T_u$ | Thermodynamic air temperature outdoors, K |
| $T_i$ | Thermodynamic air temperature indoors, K |
| $h$ | Distance to the neutral zone, m |

If $\rho_u = 1.29 \ kg/m^3$ (air density at the temperature of 273 K and 100 kPa), one obtains

$$\Delta p \approx 13 \cdot h \, (1 - \frac{T_u}{T_i}).$$

With a difference of 25 C between the outdoor and indoor air temperatures, one obtains a variation of the pressure difference over the construction, amounting to approximately 1 Pa per m elevation difference.

FIGURE 23: Pressure distribution over a wall with two openings and lower temperature outdoors than indoors.




The position of the neutral zone may vary according to existing leakages in the building. If the leakages are evenly distributed vertically in the building, this zone is close to half the height of the building. If tne number of leakages is greater in the lower parts, the neutral zone is moved downward, if there are more leakages in the upper parts, it is moved upward. A chimney opening above a roof has a great influence on the location of the neutral zone, and negative pressure may occur in the entire building. This is the most common condition in small houses.

In a larger building, of the higher industrial building type, where leakages exist around entrances and existing windows in the lower part of the building, the neutral zone is located at approximately 1/3 of the height of the building. FIGURE 24 shows examples of different air flow directions through the same construction but at different levels.

When thermographing from the inside, it is an advantage if the building has a negative pressure with equal pressure conditions throughout the various building components. Potential (air) leakage spots will show clearly and under similar conditions. The cold outdoor air will leak in through openings in the construction, and in the warm side, it will cool adjacent surface portions. On the outside, such a leakage has an insignificant effect on the temperature distribution over the wall surface, since the surface temperature is susally close to that of the air leaking in.

When there is a positive pressure in the building, the leakage points appear as warmer portions in the thermogram, both from the inside and from the outside. Under such conditions, the leakage appears more diffuse, specifically on the warmer side, where the temperature variations are usually of lesser magnitude than when the air leaks inward. This is due to the fact that the temperature difference between the air in the room and the wall surface is usually small. In the latter case, an outdoor measurement may be advantageous (see FIGURE 25).

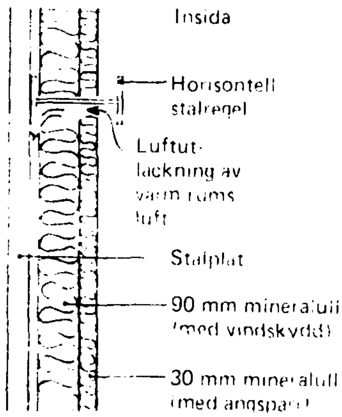
When the only deficiencies are found in the insulation, i.e. if there is no insulation material in a certain area where the construction is tight, the surface temperature of the wall is not affected by the pressure conditions over the construction. However, air leakage is the predominant type of deficiency, and consequently, the pressure conditions over the construction are normally of vital importance for thermography.

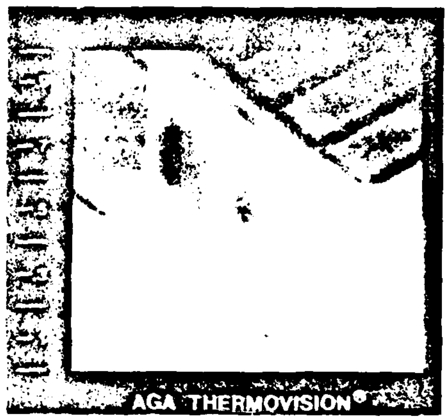
FIGURE 24: Insulation and tightness deficiencies causing air leakage through the construction. Various air flow directions through the same construction at different levels due to indoor positive pressure at the upper part of the wall and indoor negative pressure at the lower part.

Measuring conditions:

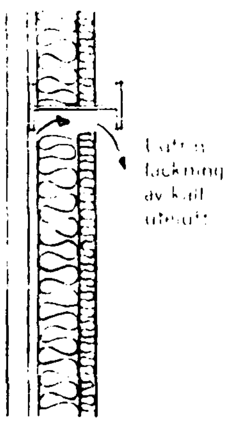
| | |
|---|---|
| Cloud cover | cloudy |
| Air temperature outdoors | -1°C |
| Air temperature indoors | +20°C |
| Wind conditions | 3 - 4 m/s (towards the facade) |
| $P_i - P_u$ | 15 Pa, upper part |
| $P_i - P_u$ | 5 Pa, lower part |

a) Thermogram from the inside of the wall on its upper part (approx. 15 m above floor level). Certain surface portions are warm due to warm room air leaking through the permeable construction.
(Text of the left hand figure: Inside: Horizontal steel bolt; Outward leakage of warm air from the room; Steel siding; 90 mm mineral wool (with wind protection); 30 mm mineral wool (with vapor barrier)




b) Thermogram from the lower part of the wall (approx. 5 m above the floor) at the same vertical line as a). Here, certain surfaces are cold due to leakage of cold outdoor air through the permeable construction.
(Text at left-hand picture: Inward leakage of cold outdoor air.



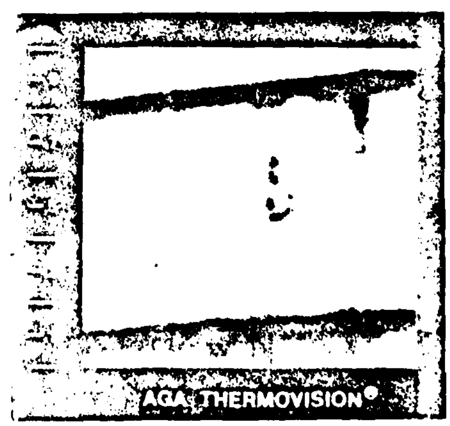


FIGURE 25: Thermograms taken of the corresponding wall portion, from both inside and outside.

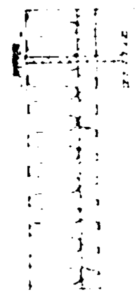
From the outside:
Horizontal wall bolt
Metal siding (painted)
90 mm mineral wool
(with wind protection)
30 mm mineral wool
(with vapor barrier)

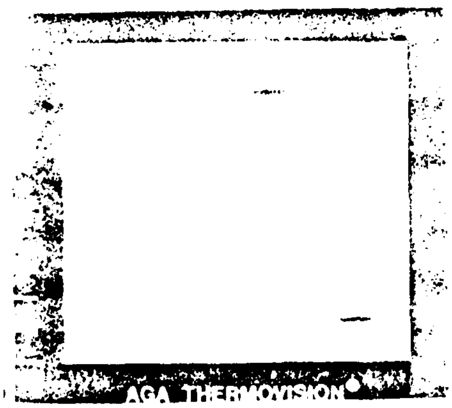
Measuring conditions:
Cloud cover: cloudy
Outdoor air temperature: - 1°C
Indoor air temperature: +19°C
Wind conditions: 3-4 m/s (approx. 45° from facade)
$p_i - p_u = + 15$ Pa

a) Construction of exterior wall with outside metal siding.

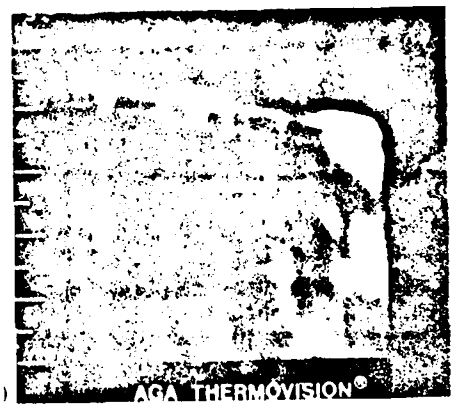
b) Thermogram of the upper portion of the wall (taken from the inside). Certain heated areas appear close to both the vertical profiles and the horizontal wall bolts. The heating is related to outward leakage of room air. Picture c) shows the corresponding wall portion thermographed from the outside.

c) Thermogram of the same surface portion as in picture b). The warm room air leaking outwards warms the metal facade surface at certain points. The wind conditions at the time cause a slight leftward distortion of the warm portions in the picture.






c)



## 3.5. Non-stationary temperature conditions

Under real-life conditions, the temperature conditions in the construction are normally of a non-stationary type.

Daily variations in the outdoor air temperature, ordinarily with higher day temperatures and lower night temperatures, will affect the temperature on the inside of the construction with a certain phase shifting as well as a certain amplitude change. The magnitude of this effect is related to the composition and heat capacity of the construction. The amount of heat stored in a construction is dependent both on the thermal characteristics of the building materials and of how rapidly a temperature fluctuation can propagate in the material. The latter can be defined by means of the temperature conduction formula as follows:

$$a = \frac{\lambda}{\rho c}.$$

If a is small, a temperature fluctuation propagates slowly. The heat penetration formula $\sqrt{\lambda c \rho}$ is a material constant indicating how rapidly heat can be stored in a material, and the higher this constant, the more heat can be accumulated within a certain period of time.

A construction is generally composed by various materials with different thermal characteristics. Wooden bolts, mineral wool, and light concrete, for instance, are often placed close to each other. An outdoor temperature change has various effects on the composition of the construction in the portion involved. FIGURE 28 shows examples of thermograms from such a portion.

Thermography should not be performed under greatly varying temperature conditions. Temperature variations increase the requirements on temperature loss over the construction for obtaining detectable differences in the heat image. In order to clarify the conditions that should be fulbilled, a numerical calculation of the surface temperature variations on the inside under varying outdoor temperatures. This calculation was done by solving the general heat conduction equation in one dimension with a simple forward differentiation method, computer aided.

The following conditions were assumed:

- One-dimensional heat flow.
- Constant (indoor) air temperature of $t_i$ = +20°C with $\alpha_i$ = 7 W/(m$^2$ · K).
- (Outdoor) air temperature varies sinusoidally over a 24-hour period according to

  $$t_{u,e} = t_u + t_i \sin \frac{\pi}{12} (\tau - 8)$$

  with $\alpha_u$ = 20 W/(m$^2$ · K) ($\tau$ = time within the 24-hour period).
- The temperature conditions are applicable during several subsequent 24-hour periods.

Calculations were made for two different constructions according to FIGURES 26 and 27.

The insulation decrease at the cuts B has been selected so that it will be possible to detect a minimal resistance decrease of 30 - 35% of the total heat resistance of the wall as appearing in the thermogram. This evaluation has been obtained from practical measurement experience. For instance, this makes it possible to detect whether a 5 cm thick insulation panel is missing in a construction with 5 + 7 cm insulation.

The calculations have been made for the following outdoor temperatures:

$$1.\quad t_u = 10 + 3 \sin \frac{\pi}{12} (\tau - 8)$$

$$2.\quad t_u = 10 + 5 \sin \frac{\pi}{12} (\tau - 8)$$

$$3.\quad t_u = 7 + 3 \sin \frac{\pi}{12} (\tau - 8)$$

$$4.\quad t_u = 7 + 5 \sin \frac{\pi}{12} (\tau - 8)$$

$$5.\quad t_u = 7 + 10 \sin \frac{\pi}{12} (\tau - 8)$$

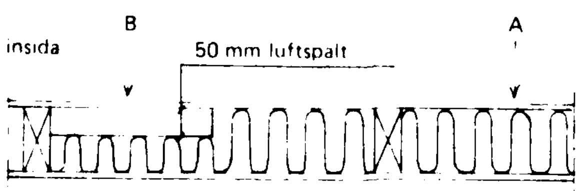
Calculations have been made for the wall surface at sections A and B at different hours. Table 3 - 5 shows examples of the results.

For wall type 1, the phase shift between maximum outdoor temperature and maximum indoor wall temperature is 1 - 2 hours. The corresponding phase sh ft for wall type 2 is 6 - 7 hours. The phase shirt between the surface temperatures at the sections A and B is 0.5 - 1.0 hours for both wall types.

FIGURE 26: Construction I of outside wall for which temperature calculation was made.

From the inside: 13 mm gypsum panel; polyethene (PE) foil; 120 mm mineral wool $\underline{p}$ = 45 kg/m$^3$; 13 mm asphalt impregnated wood fiber panel $\underline{p}$ = 300 kg/m$^3$.

Inside B 50 mm air slot A

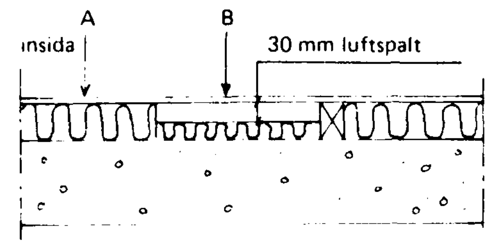



Horizontal section

FIGURE 27: Construction II of outside wall for which temperature calculation was made.

From the inside: 13 mm gypsum panel; 70 mm mineral wool, $\rho$ = 45 kg/m$^3$; 150 mm light concrete, $\rho$ = 500 kg/m$^3$; Facing plaster.

Inside A B 30 mm air slot

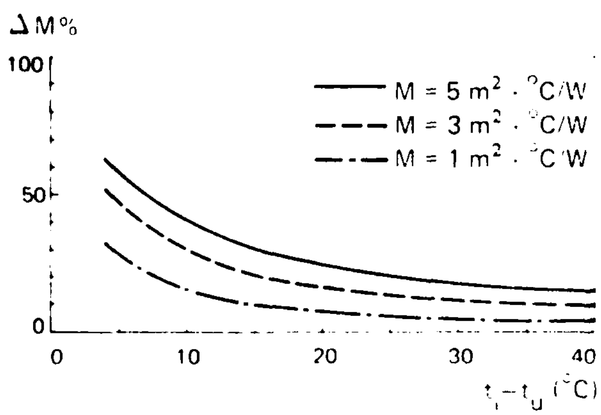



Horizontal section

For the insulation decrease at section B to be detected with the heat camera it is necessary that $t_{viA} - t_{viB} > 20°C$.

Those time periods when $t_{viA} - t_{viB} > 20°C$ have been indicated in the tables.

Establishing a minimum temperature difference at which thermography in the field is purposeful will be a factor primarily of the temperature resolution capacity of the camera and the temperature condition of the wall. The presentation below shows that insulation decrease which can barely be detected under stationary conditions at various air temperature differences (indoor/outdoor) over the construction and at different heat resistance.




Correlation between that insulation decrease which can barely be detected, in % of the heat resistance of the contruction, and the existing temperature difference (air/air) throughout the construction.

The parameter is the resistance of the construction. (In this case, it is assumed that $m_u$ = 0.05 m$^2$ °C/W, and $m_i$ = 0.15 m$^2$ °C/W.

(Paljak & Pettersson, 1972)

In the practice, insulation deficiencies are most frequently of such a character that the filling in the spaces between the studs is not complete, and this is combined with air leakage in or through the construction. Usually, this condition increases the effect of the deficiency, causing increased temperature difference on the surface of the construction. When the temperature differences over the construction are small (10 - 15° C), the temperature differences on the surface are also relatively small, and external disturbances

**TABLE 3 and 4:** Calculation of surface temperatures at different hours.

Construction type I
Measuring case 1, $t_i$ = +20°C

| hr | $t_u$ °C | $t_{vi}$ at section, °C A | B |
|---|---|---|---|
| 00 | 7.4 | 19.50 | 19.25 |
| 01 | 7.1 | 19.47 | 19.22 |
| 02 | 7.0* | 19.46 | 19.20 |
| 03 | 7.1 | 19.45* | 19.19* |
| 04 | 7.4 | 19.45* | 19.20 |
| 05 | 7.9 | 19.46 | 19.22 |
| 06 | 8.5 | 19.47 | 19.25 |
| 07 | 9.7 | 19.50 | 19.28 |
| 08 | 10.0 | 19.50 | 19.33 |
| 09 | 10.3 | 19.56 | 19.42 |
| 10 | 11.5 | 19.59 | 19.42 |
| 11 | 12.1 | 19.62 | 19.47 |
| 12 | 12.6 | 19.65 | 19.51 |
| 13 | 12.9 | 19.67 | 19.54 |
| 14 | 13.0** | 19.69 | 19.55 |
| 15 | 12.9 | 19.70** | 19.56** |
| 16 | 12.6 | 19.70** | 19.56** |
| 17 | 12.1 | 19.69 | 19.54 |
| 18 | 11.5 | 19.67 | 19.51 |
| 19 | 10.3 | 19.65 | 19.47 |
| 20 | 10.0 | 19.62 | 19.43 |
| 21 | 9.7 | 19.59 | 19.38 |
| 22 | 8.5 | 19.56 | 19.33 |
| 23 | 7.9 | 19.52 | 19.29 |
| 24 | 7.4 | 19.50 | 19.25 |
| | | 19.58 | 19.38 |
| | | ±0.12 | ±0.19 |
| | 10 | 19.58 | 19.38 |

Under static conditions

Construction type II
Measuring case 5, $t_i$ = +20°C

| hr | $t_u$ °C | $t_{vi}$ at section, °C A | B |
|---|---|---|---|
| 00 | -1.7 | 19.52 | 19.33 |
| 01 | -2.7 | 19.48 | 19.26 |
| 02 | -3.0* | 19.43 | 19.17 |
| 03 | -2.7 | 19.37 | 19.09 |
| 04 | -1.7 | 19.32 | 19.00 |
| 05 | -0.1 | 19.27 | 18.93 |
| 06 | +2.0 | 19.22 | 18.87 |
| 07 | +4.4 | 19.19 | 18.83 |
| 08 | 7.0 | 19.17 | 18.8[illegible]** |
| 09 | 9.6 | 19.16* | 18.8[illegible] |
| 10 | 12.0 | 19.17 | 18.8[illegible] |
| 11 | 14.1 | 19.19 | 18.87 |
| 12 | 15.7 | 19.22 | 18.94 |
| 13 | 16.7 | 19.27 | 19.01 |
| 14 | 17.0** | 19.32 | 19.09 |
| 15 | 16.7 | 19.37 | 19.18 |
| 16 | 15.7 | 19.43 | 19.26 |
| 17 | 14.1 | 19.48 | 19.34 |
| 18 | 12.0 | 19.52 | 19.40 |
| 19 | 9.6 | 19.55 | 19.44 |
| 20 | 7.0 | 19.57 | 19.46** |
| 21 | 4.4 | 19.58** | 19.46** |
| 22 | 2.0 | 19.57 | 19.44 |
| 23 | -0.1 | 19.55 | 19.39 |
| 24 | 1.7 | 19.52 | 19.33 |
| | | 19.37 | 19.1[illegible] |
| | | ±0.21 | [illegible] |
| | 7 | 19.37 | |

Under static conditions

* min. ** max.

may then significantly affect the measurement result. Thus, a higher degree of temperature stability in the ambient air is required when the temperature differences throughout the construction are small than when they are great.

### 3.5.1. The effect of sun on thermography

For orientation purposes, exploratory field measurements were performed in order to clarify how sun and varying outdoor temperatures affect the temperature image on the inside of the wall.

If the wall surface in a room is exposed to direct sunlight, there is an immediate heating of the surface, and potential temperature variations tend to be equalized. If the sun hits the outside of the facade, there is a temperature increase on the inside of the wall after a certain time and of a magnitude related both to the wall construction and to the intensity of the sun, FIGURE 28.

In a test apartment in a multiple dwelling, a portion of an outside wall was thermographed under varying conditions. From the inside, the construction of the outside wall consisted of: 13 mm gypsum panel, 0.13 mm polyethene (PE) foil, 120 mm mineral wool (50 x 120 mm wooden studs), 12 mm asphalt impregnated wood fiber panel, and facing. In one area, to the left of the window as seen from the inside (see FIGURE 29 a), the insulation thickness was reduced to approximately 50% of the original thickness. The wall portion in question was partially screened from sun exposure due to the shadow of a balcony.

Thermography of this portion was performed from the inside at different hours of the day, and under varying measurement conditions.

The studies showed that during typical fall and winter days with moderate 24-hour variations of the outdoor air temperature, approximately $\pm$ 3°C, there are no major changes in the heat image appearance for such a surface portion. At these measurements, $t_i - t_u$ was $>$ 15°C. In a natural way, the surface temperature of the cooled surface portion will follow the outdoor variation. The effects of the variations will not be so great as to cause difficulties in the interpretation, FIGURE 29.

On a typical spring day with relatively low night temperature of $\pm$ 0 C and a higher day temperature of approximately + 14°C with simultaneous sun radiation on portions of the facade, measurements with heat camera are difficult and uncertain.

The measurements showed that temperature contrasts at the deficient wall portion were relatively rapidly equalized, and the deficiency was masked during the greater part of the day. The result is partially shown in the thermograms in FIGURE 30.

As has been previously mentioned, thermography should not be performed when sun radiation has affected the building portion. Occasional sun radiation can be acceptable if it is considered not to affect the result. Thus, windows should, for example, be covered in order to prevent direct sunshine into the room.

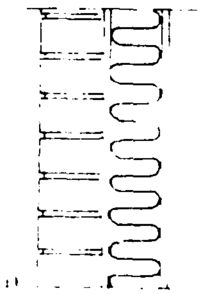
In conjunction with thermography of buildings, one should determine the maximum and minimum temperatures at the measurement location for 24 hours prior to the thermography, e.g. by means of a maximum thermometer. One should also be familiar with the sun conditions during that 24-hour period.

FIGURE 28: Thermograms taken of outside wall (towards the south) which has been exposed to sun.

From the outside: Facing brick, asphalt impregnated wood fiber panel, 95 mm mineral wool, (2" x 4" wooden studs), polyethene (PE) foil, 13 mm gypsum panel.

Measuring conditions:

| | |
|---|---|
| Cloud cover | clear (sun affects portions of the outside wall) |
| Outdoor air temperature | + 6°C |
| Indoor air temperature | + 20°C |
| Wind conditions | calm |
| $P_i - P_u$ | - 5 Pa |



Inside

a) Construction of outside wall.

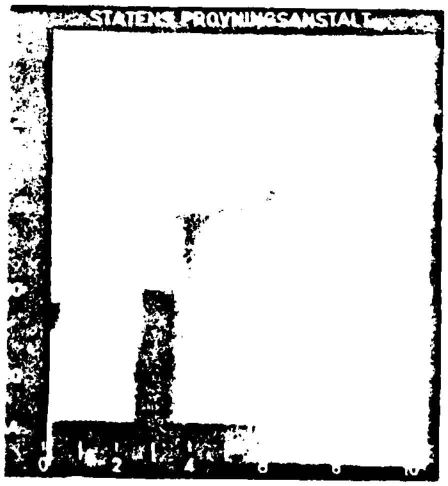
b) Thermogram of surface portion at wall (towards the south) which has been exposed to sun for 3 - 4 hours. The darker portion close to the ceiling angle is caused by shadow from an extending roof portion.

c) Isotherm image

$t_{ref}$ = + 19°C

$\Delta 1$ = - 2.7 isotherm units
$\Delta t$ = 4.0°C
v = 0 m/s

b)




c)

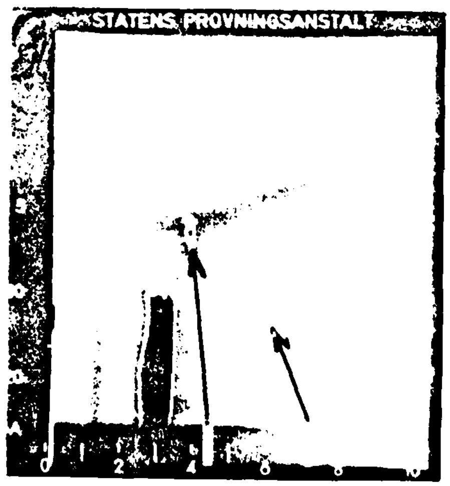


FIGURE 29: Thermogram taken from the inside under varying outdoor temperature conditions

a) Exposed wall portion from the outside, where the insulation was reduced by approx. 50%.

b) Thermogram taken from the inside of the wall portion under a), to the right of the window. The cooled portion had the same appearance during the entire 24-hour period under the previously mentioned weather conditions. The degree of cooling of the deficient wall portion varied slightly.

c) $t_i = +23°C$

$t_u = +5°C - +7°C$ (variation during the 24-hour period, not affected by the sun)

$\Delta t = 3.0\ °C$

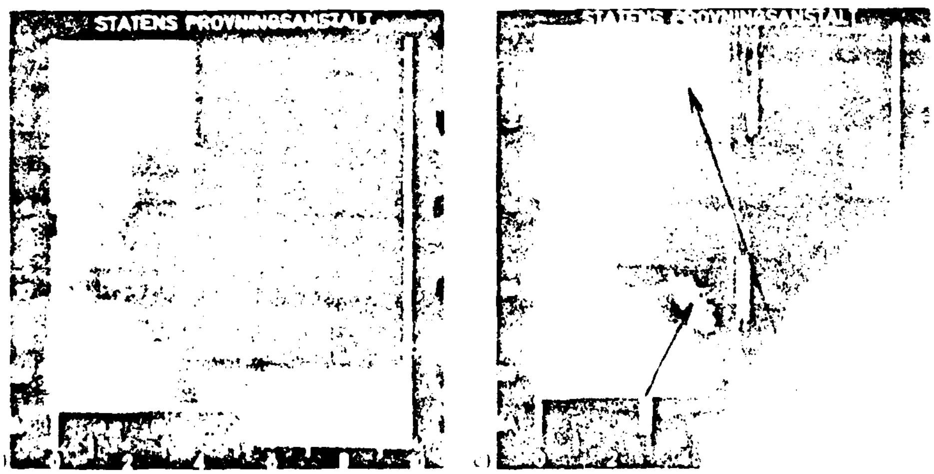


FIGURE 30: The effect of the sun on the appearance of the heat image.

a) Sun on the facade at 9:00 a.m. The surface portion with reduced insulation has been marked.

b) Sun on the facade at 3:00 p.m. The surface portion with reduced insulation has been marked.

c) Thermogram at 9:00 a.m.

$t_i$ = + 23°C

$t_u$ = + 6°C

$t_{vu}$ = $\approx$ + 35°C (surface exposed to sun)

d) Thermogram at 12:00 noon

$t_i$ = + 24°C

$t_u$ = + 11°C

$t_{vu}$ = approx. + 40°C (surface exposed to sun)

e) Thermogram at 3:00 p.m.

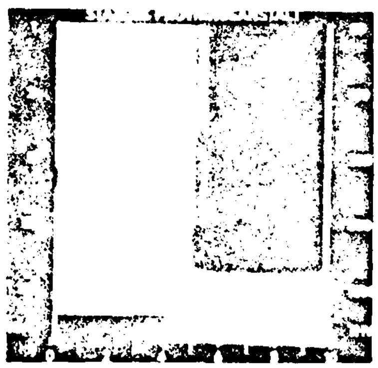
$t_i$ = + 24°C

$t_u$ = + 14°C

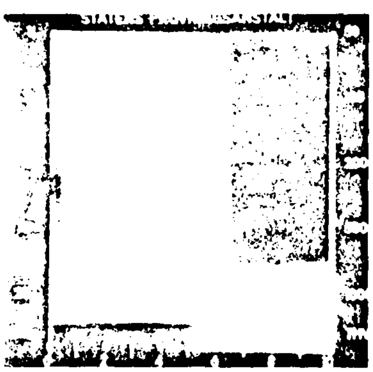
$t_{vu}$ = approx. + 40°C (surface exposed to sun)

a)

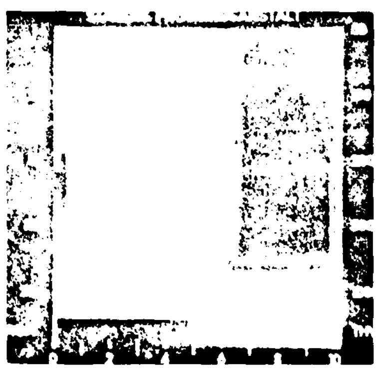
b)



c)



d)



e)

# 4. APPLICATIONS OF THERMOGRAPHY

## 4.1. Measuring conditions and measuring season

On the basis of the preceding text, the following summary can be given concerning the requirements on measuring conditions for thermography of buildings.

Thermography is to be performed so as to minimize disturbing effects from external climate factors. Thus, measurements are to be made indoors, i.e. the warm surface is investigated in a heated building.

Outdoor thermography is performed only for exploratory measurements of larger facade surfaces. In certain cases, e.g. where the heat insulation is very bad or where there is an indoor positive pressure, outdoor measurements may be valuable. Thermography from the outside of a building may also be justified for study of the effect of installations placed in the climate screen of the building.

The following conditions should be fulfilled:

1. For at least 24 hours prior to the thermography and for its entire duration, the air temperature differences thoughout the building portion is to be at least 10°C. For the same duration of time, the air temperature difference may not vary be more than $\pm$ 30% of the difference at the outset of thermography. During the course of the thermography investigation, the indoor air temperature should not change more than $\pm$ 2°C.

2. For at least 12 hours prior to the thermography and for the entire duration of the measurements, no direct sun may fall on the building portion under study.

3. Pressure drop throughout the construction $\approx$ 5 Pa.

4. The requirements on the measurement conditions may be somewhat relaxed if the purpose of the thermography is only to locate air leakages in the portions enclosing the building. A difference of approximately 5°C between the indoor and outdoor air temperature may be sufficient for detection of such deficiencies. However, certain demands on the pressure difference must be fulfilled; approximately 5 Pa should be sufficient.

The above-mentioned requirements on the measuring conditions limit the period of the year, during which thermography can be performed in Sweden.

According to statistics from SMHI (Swedish Meteorological and Hydrological Institute) concerning average values for maximum and minimum temperatures for each day and each month January - December over a 30-year period 1931, 1960, the length of the measuring season can be estimated - Table 5. For the locations of Kiruna, Stockholm, and Lund, the following periods will be obtained, during which thermography with an indoor temperature of + 20°C can be performed according to the above condition 1:

Kiruna: Middle of September - middle of May (approximately 8 months)

Stockholdm: Early October - end of April (approximately 6.5 months)

Lund: Middle of October - middle of April (approximately 6 months)

The effect of the sun has not been considered. The measuring season can be prolonged, if the indoor temperature is increased.

When the purpose of the measurements is merely to locate air leakage in the building, the requirements on measuring conditions may be somewhat relaxed, which prolongs the period for utilizing the heat camera. In such measurements, it is not necessary to fulfill the requirement of maximum variation of temperature difference being ± 30%. However, the pressure difference requirement throughout the construction remains in effect. Leakage search with IR camera should be performed from the inside of the building and with indoor negative pressure.

TABLE 5: Average values for maximum and minimum temperatures 1931 - 1960 according to SMHI.

| | Kiruna | | Stockholm | | Lund | |
|---|---|---|---|---|---|---|
| | max | min | max | min | max | min |
| jan | - 8,2 | - 17,1 | - 1,0 | - 4,7 | + 1,1 | - 2,8 |
| feb | - 8,3 | - 17,0 | - 1,2 | - 5,5 | + 1,4 | - 3,2 |
| mar | - 4,3 | - 14,4 | + 1,9 | - 3,6 | + 4,6 | - 1,5 |
| apr | + 0,5 | - 8,5 | + 8,3 | + 0,7 | + 10,6 | + 2,5 |
| maj | + 6,7 | - 1,4 | + 14,6 | + 5,7 | + 16,7 | + 6,7 |
| jun | + 13,7 | + 4,7 | + 19,2 | + 10,4 | + 20,6 | + 10,6 |
| jul | + 17,6 | + 8,4 | + 21,8 | + 14,0 | + 22,4 | + 13,1 |
| aug | + 14,9 | + 6,2 | + 20,2 | + 13,3 | + 21,3 | + 12,7 |
| sep | + 8,7 | + 1,9 | + 15,3 | + 9,4 | + 17,1 | + 9,8 |
| okt | + 1,5 | - 4,6 | + 9,0 | + 4,8 | + 10,7 | + 5,8 |
| nov | - 3,6 | - 10,7 | + 4,5 | + 1,0 | + 6,6 | + 2,5 |
| dec | - 6,4 | - 14,6 | + 1,9 | - 1,9 | + 3,1 | - 0,2 |

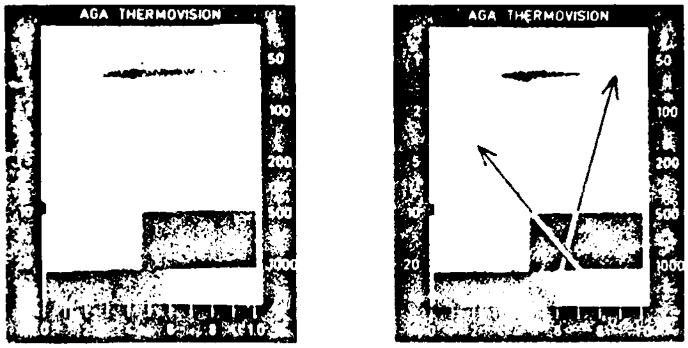
## 4.2. Interpretation of thermograms

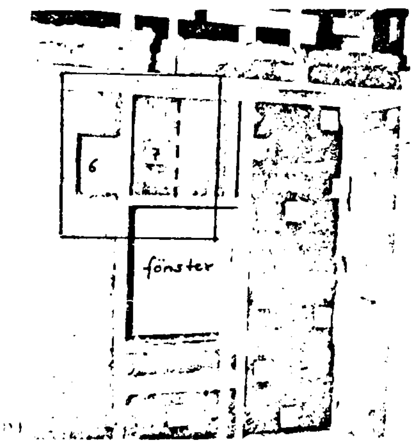
The major purpose of thermography is to locate errors and deficiencies of heat insulation in outside walls and beam tiers and to determine the type and extent of the error. The measuring task can also be defined as confirming by means of thermography that the investigated wall possesses the specified insulation and tightness characteristics. The "specified heat insulation characteristics" for the wall according to drawing can be transferred into an expected surface temperature distribution for the investigated surface, if the conditions at the time of measurement are known.

In the practice, the method means:

An expected temperature distribution is prepared in advance, either in laboratory tests or in field tests, in the form of a "type of comparative thermogram" covering frequently occurring wall constructions and containing both perfect constructions and constructions with built-in deficiencies. FIGURE 31 shows examples of type thermograms.

FIGURE 31: Use of comparative thermograms.




a) Type thermogram of a surface portion at a ceiling angle of studded wall No. 1 in an error-free construction.

$t_i - t_u = +26°C$ $t_{ref} = +20°C$
$p_i - p_u = -50$ Pa $\Delta t = 2.7°C$

b) Studded wall No. 1 with gypsum panel and plastic foil removed. The location of different errors is indicated. Note particularly errors 6 and 7, where the insulation thickness is reduced by 100 adn 50% of the original.

c) Type thermogram of surface portion at a ceiling angle for studded wall No. 1 with built-in deficiencies. Notice errors 6 and 7. There is an air leakage through an imperfect connection at the ceiling.

$t_i - t_u = +26°C$ $t_{ref} = +20°C$
$p_i - p_u = -50Pa$ $\Delta t = 4.1°C$

In order to use field measured thermograms of a construction portion as comparative thermograms, the structure of the building, the workmanship, and the measuring conditions must be well known and documented.

In order to discuss the reasons for deviations from the expected results of thermography, it is necessary to know the conditions of physics, measurement techniques, and construction technology.

Briefly, the interpretation of field measurement thermograms can be described as follows:

A comparative thermogram for correct construction is selected on the basis of the wall construction of interest and the conditions at the time of the field measurement. The thermogram for the investigated building portion is compared with the selected thermogram. Deveiations which cannot be explained on the basis of the construction or the measuring conditions will be noted as suspected insulation deficiencies. The nature and extent of the deficiencies is normally determined with the aid of comparative thermograms showing various deficiens. The principle for thermogram interpretation is shown in a block diagram on p. .

If there are no suitable comparative thermograms, the evaluation must be based on experience. For this, a more careful reasoning is required in the analysis.

When evaluating a thermogram, the following should be investigated.

- Evenness in the color tone in thermograms of surface portions with no cold bridges.

- Regularity and appearance of cooled surface portions (dark grey tone) e.g. at studs and bolts and in corners.

- Outline and characteristic shape of the cooled surface portion.

- Measured temperature difference between the normal surface temperature of the construction and the selected cooled surface portion.

- Continuity and evenness of the isotherm curve on the surface of the construction.

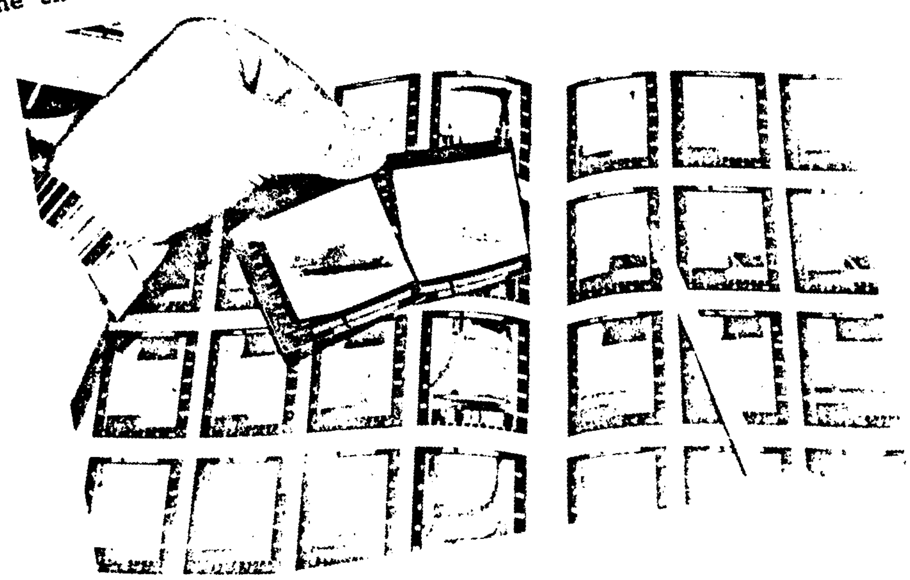
Deviations and irregularities in the appearance of a thermogram frequently indicate an insulation deficiency. Naturally, the appearance of thermograms from the construction with insulation deficiency can vary greatly. Certain types of insulation deficiencies have a characteristic shape in the thermogram. FIGURE 32 shows examples of thermogram interpretation.

In the thermography of the same object, it should be attempted to take the thermograms of various portions with the same adjustment of the heat camera. This makes it easier to compare different surface portions. When a surface portion is studied, it is customary to take one grey-tone picture and one isotherm picture of the same portion. The isotherms are entered on the selected portions of the construction surface. The reference temperature corresponding to one istherm is determined, e.g. with a surface thermomenter. In this manner, temperature differences between different surface portions can also be determined.

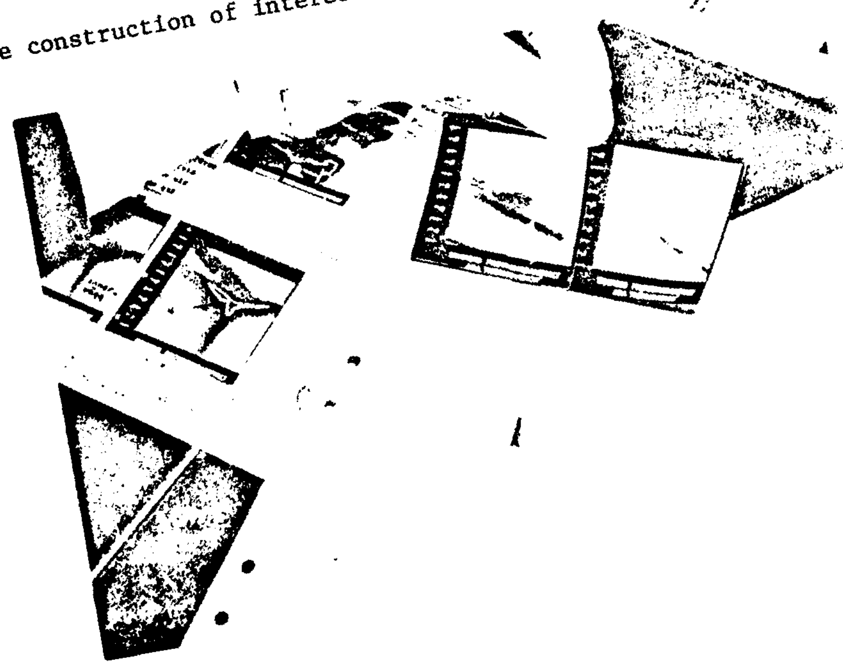
The described principle for heat image interpretation applies primarily to black and white thermograms, which are most common. However, color thermo-

FIGURE 32:

a) The thermograms are compared with type thermograms.



b) The construction of interest is studied.



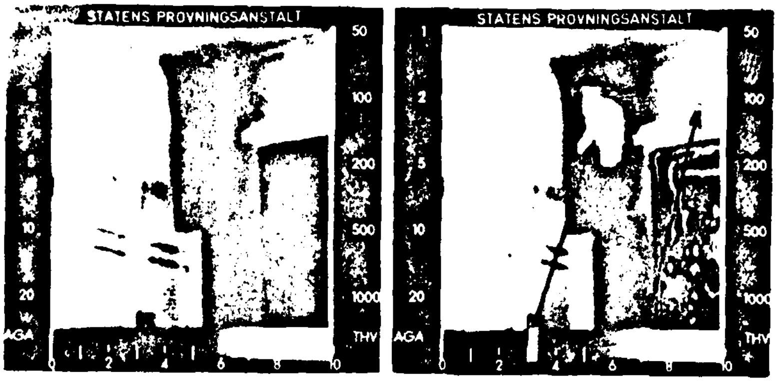
c) Thermogram of surface portion of outside wall at ceiling angle. Cooled (dark) portion appear in the thermogram to the left of the window (grey tone image to the left, isotherm image to the right)

$t_i - t_u$ = +21°C

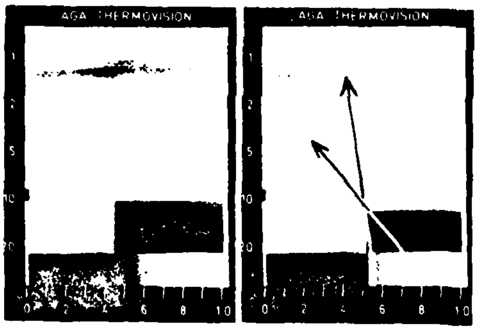
$p_i - p_u$ = - 3 Pa

$t_{ref}$ = +21°C

t = 2.5°C (difference in surface temperature between "normal" wall temperature and cooled surface portion.




c)

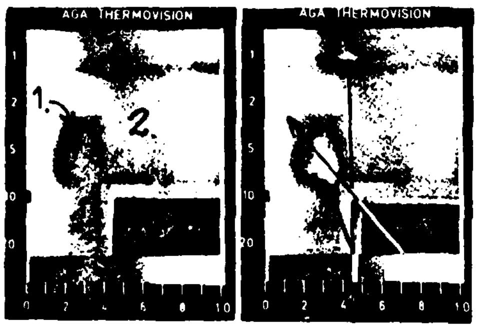



d)

d) Type thermogram for outside wall with basically the same construction (studded wall No. 1) as the one in c) and under the following measuring conditions:

$t_i - t_u$ = + 26°C   $t_{ref}$ = + 20°C

$p_i - p_u$ = 0 Pa   t = 3.0°C




e)

e) Type thermogram for the same outside wall as in d) but with built-in deficiencies. The same measuring conditions as under d).

t = 4.0°C

Comparison between thermograms for c) and d).

Error No. 1 corresponds to 100% insulation reduction in the wall.

Error No. 2 corresponds to 50% insulation reduction in the wall.

Conclusion: Probably, there is no insulation at the cooled surface portion in c).

grams can be evaluated in the same manner. In our investigations, we have mainly used black and white thermograms for the following reasons:

- Details and temperature variations appear with great clarity in black and white thermograms.

- The equipment for producing black and white thermograms is less expensive than for the color thermograms.

- The procedure and the cost for reproducing the obtained material are simpler and lower for black and white thermograms.

FIGURE 33 b) shows an example of color thermogram.

## 4.3. Camera adjustment

In thermography, it is important that the adjustment of the IR camera allows correct light and contrast in the heat image. The directions of the manufacturer are to be followed.

Thermogram taken with different camera adjustments are shown in appendix, FIGURE 124. When adjusting the IR camera for a suitable measuring area, it is important that the temperature variations to be presented do appear as clearly as possible. If the measuring range is selected with too high sensitivity, there is a great risk that the cooled portions appear too dark, which makes it difficult to distinguish details in the image. However, a high degree of sensitivity may be required for detailed studies of e.g. insulated outside wall portions.

The main principle in adjustment of a suitable measurement range is that the range should include the temperature range of the measurement area under study.

It is also important that the aperture of the IR camera is correctly set and is not changed during the course of the thermography exposures. This setting is to be f/1.8 for the camera type that we have used.

## 4.4. The reliability of the measurement method

In some 150 cases, deficiencies located by means of the heat camera have been carefully verified either by means of opening the wall portion for visual inspection or by supplementary measurements according to other methods, e.g. heat flow measurement. Such verification methods have been mentioned previously, in Chapter 2.

It is of vital interest that no significant insulation deficiencies remain undetected, and also that the deficiencies located by means of thermography are true insulation and tightness deficiencies.

FIGURES 34 - 40 show some examples of careful verification of thermography results.

Each measuring case is reported on a page containing thermogram of the building portion in question, the appearance of the construction, and the applicable measuring conditions. In addition, there is a report on the methodology applied for verification of the IR camera recording in the case.

The thermograms are combined in groups of two, where that thermogram indicating the temperature distribution according to the grey tone scale

Procedure for interpretation of thermogram:

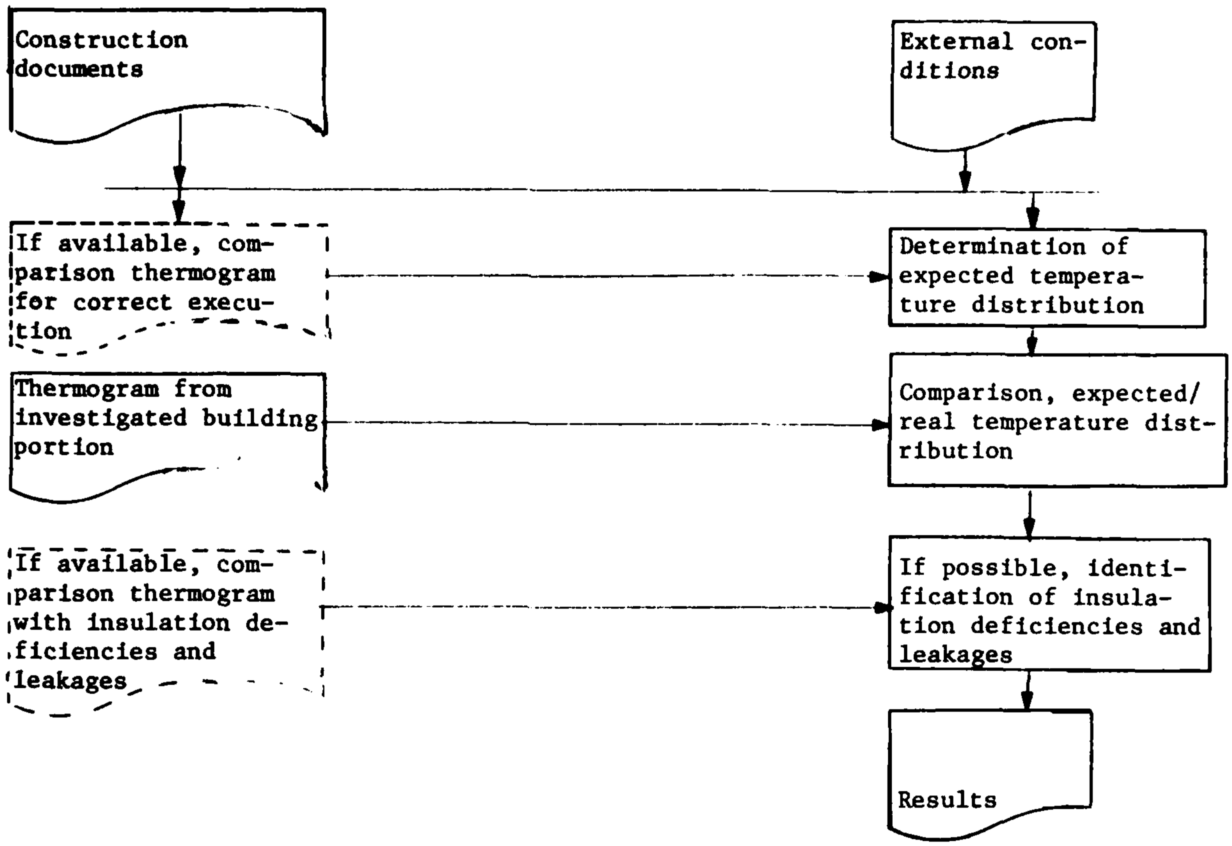


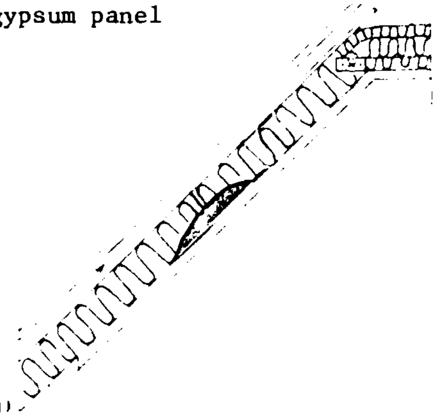
FIGURE 33: Color thermograms and black/white thermograms from the same surface portion.

Sloping roof, from the top:

Roof covering
Underlayer
19 mm tongue and groove
3 mm particle board
108 mm mineral wool
Polyethene (PE) foil
13 mm gypsum panel

Measuring conditions:

| | |
|---|---|
| Cloud cover: | Clear (thermographed building portion not affected by sun) |
| Outdoor air temp.: | - 2°C |
| Indoor air temp.: | + 21°C |
| Wind conditions: | Calm |
| $p_i - p_u$: | - 5 Pa |



a) Construction of insulated sloping roof portion with deficient insulation.

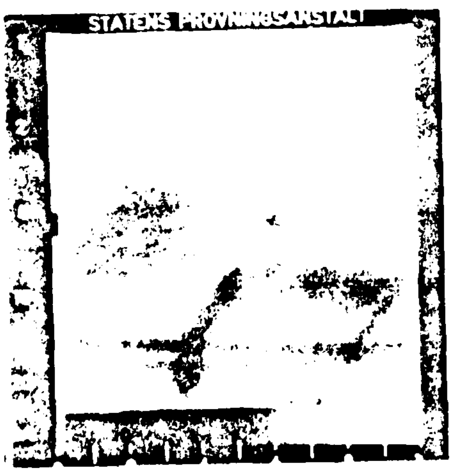
b) Color thermogram of sloping roof portion.
Upper temperature limit for color:

| | |
|---|---|
| white .................. | + 21.0°C |
| yellow ................. | + 20.4°C |
| red .................... | + 19.7°C |
| purple ................. | + 19.0°C |
| light green ............ | + 18.4°C |
| dark green ............. | + 17.7°C |
| light blue ............. | + 17.0°C |
| dark blue .............. | + 16.3°C |

c) Thermogram (grey tone image) of the same surface portion as color thermogram in b). The cooled (dark) portions are related to dericient insulation.

d) Isotherm image:

$t_{ref}$ = + 20°C
$\Delta I$ = - 1.2 isotherm umits
$\Delta t$ = 1.5°C
v = 0 m/s




d)

(grey tone image, no isotherms entered) is placed to the left on the page, and the thermogram of the same surface portion with the two isotherms entered (isotherm image) to the right on the page. Arrows are drawn between the isotherm markings on the scale of the isotherm images, and the corresponding surface portion in the image.

The following desigaations have been used:

| | |
|---|---|
| $t_{ref}$ | Measured reference temperature on the selected surface portion, °C. |
| $\Delta I$ | Difference obtained between the isotherm markings on the isotherm image, isotherm units |
| $\Delta t$ | Temperature difference corresponding to $\Delta I$, °C |
| $p_i - p_u$ | Pressure drop throughout construction portion, measured with a U-tube manometer, Pa |
| v | Air speed at the leakage point (at the surface), measured with hot-thread anemomenter, m/s. |

The air temperatures are measured by means of mercury thermometer. The reference temperature on the surface has been measured with a surface thermomenter.

The investigations have shown that in all cases where insulation deficiency or air leakage has been located with the aid of the IR camera, such a deficiency could also be verified in a careful checking. In our investigations, the IR camera has caused no erroneous evaluations in cases where the measurement conditions have been fulfilled.

The following can be said concerning the risk of erroneous interpretation:

With great certainty, we know the appearance of thermograms from correct constructions. There is little risk that significant errors will remain undetected, if the measurement conditions are fulfilled. However, it should be pointed out that the heat camera has difficulties in detecting an evenly underdimensioned insulation of a construction. A certain indication can be found in comparing e.g. the temperatures of the inside and outside walls, and by estimating the influence of the temperature drop on the outside wall. In such cases, a supplementary measurement may be necessary. Deficiencies of the air leakage or insufficient insulation filling type in combination with convective air movements in the construction are effectively detected, particularly if there is a negative pressure in the building.

Due to its good ability to detect insulation deficiencies, the thermography method has been used in conjunction with legal conflicts between buyer and seller of a building. In our investigations to date, thermography has been used in some 50 conflicts of this nature. Some cases have been settled in court, whereby great emphasis has been placed on the thermography results. Experience has shown that most cases have been settled by arbitration. In cases of serious deficiencies, these have been corrected, generally without cost to the buyer.

In order to perform correct thermography, it is essential to have specific knowledge and experience not only in heat camera technique but also construction technology and measurement techniques. Correct interpretation and evaluation of the results also requires experience and knowledge of construction physics and the technology of heating, water, and sanitary applications.

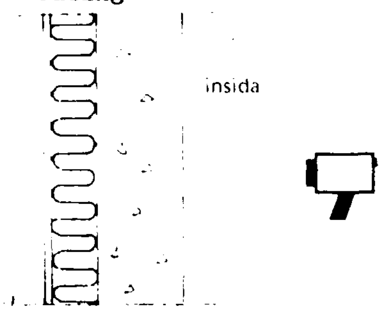
RELIABILITY OF MEASUREMENT METHOD - OUTSIDE WALL

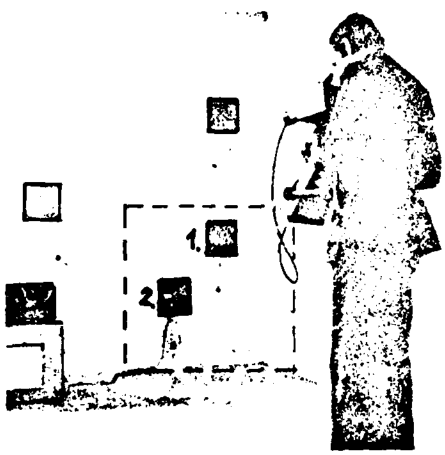
<u>FIGURE 34</u>: Investigation of the heat insulation capacity of an outside wall, by means of heat flow measurement as well as thermography. (The results of the heat flow measurement correspond well to those from the thermography.

---

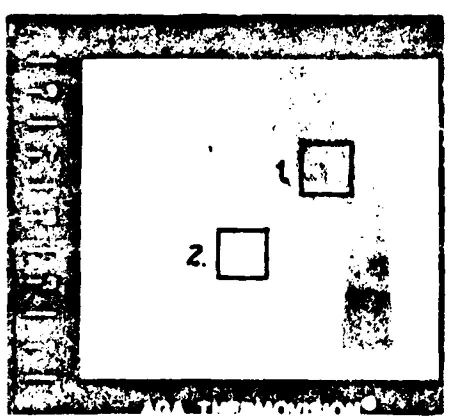
Outside wall, from the outside:

Metal siding
80 mm mineral wool
160 mm concrete
Facing



b)



c)

Measuring conditions:

| | |
|---|---|
| Cloud cover: | Cloudy |
| Outdoor air temperature: | - 1°C |
| Indoor air temperature: | + 23°C |
| Wind conditions: | approx. 3 m/s (from facade) |
| $p_i - p_u$: | - 3 Pa |

a) Outside wall construction

b) Testing arrangement with simultaneous measurement with heat flow register and IR camera on outside wall. The heat flow registers, e.g. 1 and 2, have been marked, as well as the thermographed surface portion.

Measured heat flow at points 1 and 2:

Measuring point 1 14.7 $W/m^2$
Measuring point 2 9.8 $W/m^2$

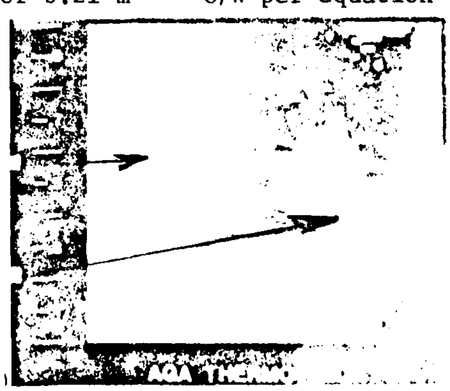
k-valueat measurement points determined as

Measuring point 1 0.60 $W/m^2$ °C
Measuring point 2 0.40 $W/m^2$ °C

c) Thermogram of partially cooled surface portion, marked in b). Probably, the cooling is related to insufficient filling of insulation material, combined with convective air movement in the construction.

d) $t_{ref}$ = + 22°C
$\Delta$ I = - 0.7 isotherm units
$\Delta$ t = 1.0°C (measurement point 1 - 2)
v = 0 m/s

$m_i$-value of 0.21 $m^2 \cdot$ °C/W per equation 3.19.



d)

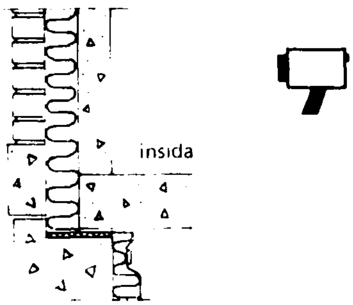
RELIABILITY OF THE MEASUREMENT METHOD - OUTSIDE WALL

FIGURE 35: Investigation of heat insulation capacity of outside wall by heat flow measurement as well as thermography. (The results of the heat flow measurements corresponds well with those from thermography.)

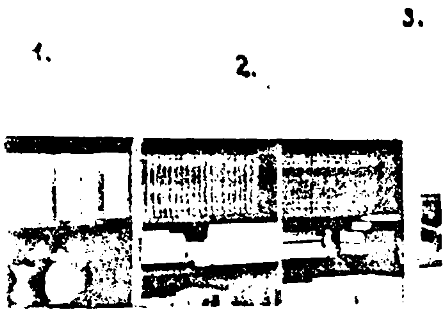
---

Outside wall, from the outside

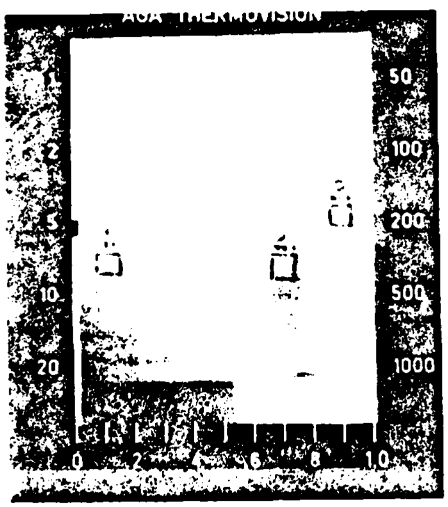
Brick facing
120 mm mineral wool
120 mm concrete




a)




b)




c)

Measurement conditions:

| | |
|---|---|
| Cloud cover: | Cloudy |
| Outdoor air temperature: | - 1°C |
| Indoor air temperature: | + 20°C |
| Winc conditions: | Calm |
| $P_i - P_u$: | - 10 Pa |

a) Construction of outside wall.

b) The heat flow registers at points 1, 2, and 3 on the ouside wall have been indicated.
k-value at each measuring point determined as being

$k_1 = 0.45\ W/m^2\ °C$

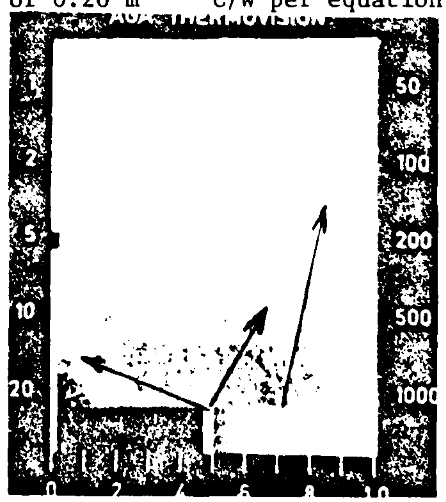
$k_2 = 0.80\ W/m^2\ °C$

$k_3 = 0.30\ W/m^2\ °C$

c) Thermogram of partially cooled surface portion in center of wall. The cooling is probably related to insufficient filling with the insulation material. The insulation panels seem to be carelessly fitted to each other and do not touch the concrete.

d) $t_{ref} = + 19°C$
$I = 1.1$ isotherm units (measurement points 1 - 2)
$t = 1.5\ °C$
$v = 0\ m/s$

$m_i$-value of $0.20\ m^2 \cdot °C/W$ per equation 3.19.




d)

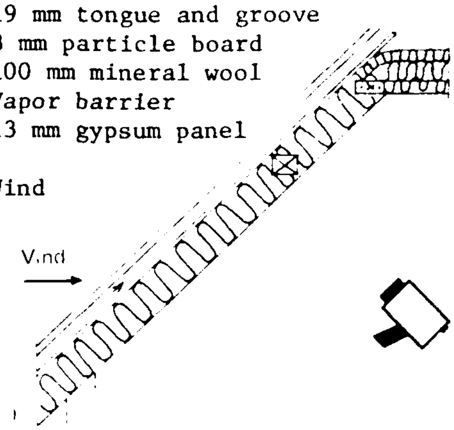
RELIABILITY OF MEASUREMENT METHOD - ROOF

FIGURE 36: Investigation of heat insulation capacity of surface portion of roof, where a suspected deficiency has been verified - insufficient filling with insulation material in combination with unsatisfactory wind protection.

Roof, from above

Roofing
Underlayer
19 mm tongue and groove
3 mm particle board
100 mm mineral wool
Vapor barrier
13 mm gypsum panel

Wind




Measuring conditions:

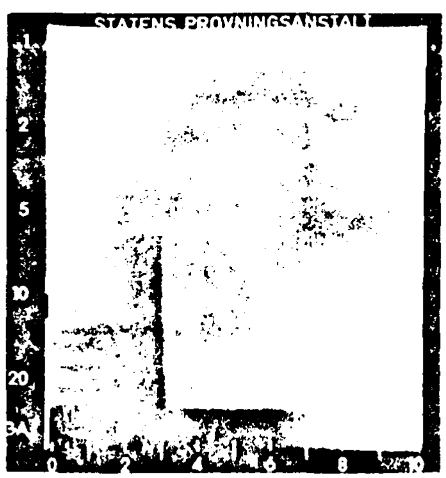
| | |
|---|---|
| Cloud cover: | Clear |
| Outdoor air temperature: | ± 0°C |
| Indoor air temperature: | + 20°C |
| Wind conditions: | 2 - 3 m/s (perpendicular to roof) |
| $p_i - p_u$: | - 5 Pa |

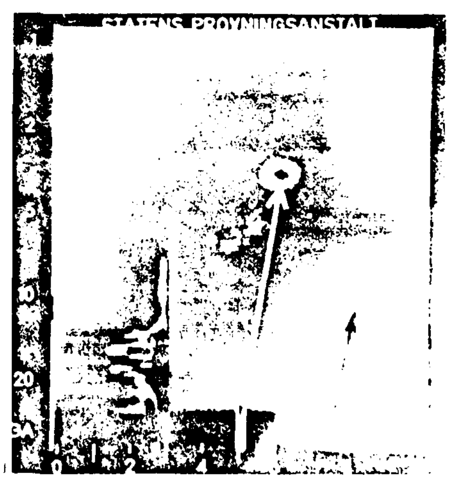
a) Construction of insulated roof.

b) Roof portion, opened from the inside. The insulation material is insufficiently filled against studs and gypsum panel. (Complicated construction.)

c) Thermogram of surface portion of sloping roof - cooled area to the right of the window portion. The cooling is related to deficiencies according to b).

d) $t_{ref}$ = + 19°C
$\Delta I$ = - 2.6 isotherm units
$\Delta t$ = 3.5°C
$v$ = 0 m/s

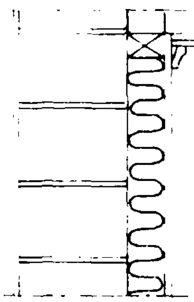


RELIABILITY OF MEASUREMENT METHOD - OUTSIDE WALL

FIGURE 37: Investigation of heat insulation capacity in surface portion of outside wall of hollow concrete blocks where a suspected deficiency has been verified by opening and visual inspection - bad fitting and filling of insulation material in the construction.

Intermediate joists

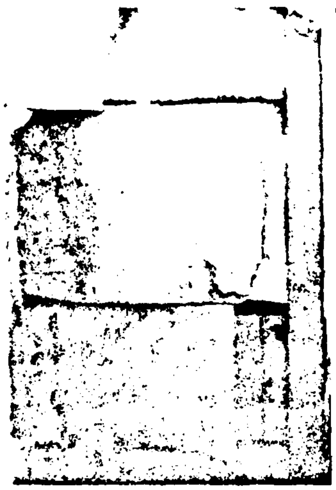



a)

Outside wall, from outside:

Concrete facing
200 mm hollow concrete blocks
70 mm mineral wool
13 mm gypsum panel

inside



b)

Measuring conditions:

Cloud cover: clear
Outdoor air temperature: + 5°C
Indoor air temperature: + 21°C
Wind conditions: 2 - e m/s (towards the facade)
$p_i - p_u$: - 5 Pa

a) Construction of outside wall.

b) Wall portion opened from the inside. Insulation material consisted of smaller pieces insulation panel with unsatisfactory fitting in the areas between the studs. Inward air leak in the construction had caused dirt on the insulation material.

c) Thermogram of partially cooled wall portion. The cooling is located at the vertical wall stud and the upper part of the wall.

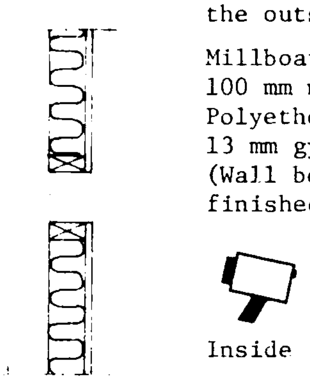
d) $t_{ref}$ = + 20°C
$\Delta I$ = - 1.2 isotherm un: s
$\Delta t$ = 1.5 °C
v = 0.5 m/s (at the roof angle)

c)

d)

RELIABILITY OF MEASURING METHOD - OUTSIDE WALL

FIGURE 38: investigation of heat insulation capacity of outside wall portion where a suspected deficiency has been verified by opening the wall - bad filling with and partial absence of insulation material.



Outside wall, from the outside:

Millboard
100 mm mineral wool
Polyethene (PE) foil
13 mm gypsum panel
(Wall borders to unfinished attic area)

Inside

Measurement conditions:

Cloud cover: cloudy
Outdoor air temperature: + 1°C
Indoor air temperature: + 23°C
Wind conditions: 1 - 2 m/s (towards facade)
$p_i - p_u$: - 5 Pa

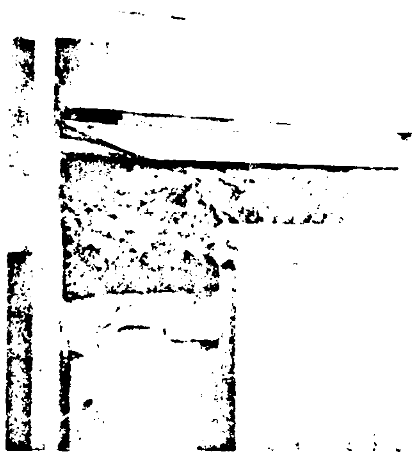
a) Construction of outside wall at parapet.

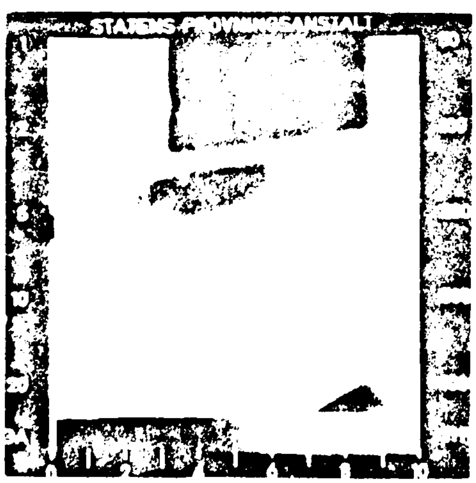
b) Opened wall section. Bad filling, partial absence of insulation material.

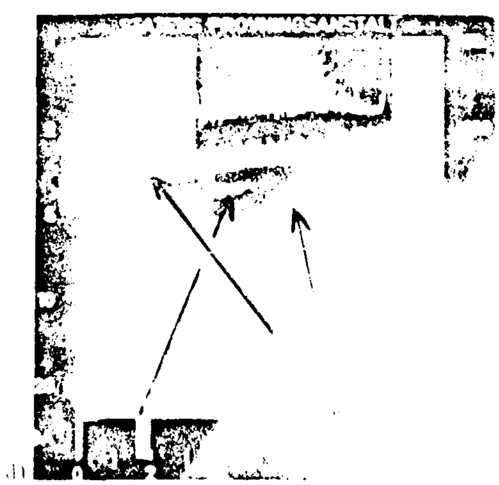
c) Thermogram of wall portion taken from the inside. Cooled surface appears at lower edge of window. Cooling caused by deficiency according to b) in combination with air movement in the construction is relatively limited in extent.

d) $t_{ref}$ = + 20°C
$\Delta I$ = - 2.7 isotherm units
$\Delta t$ = 3.5°C
$v$ = 0.5 - 0.7 m/s (locally at the window frame.

NOTE: Certain disturbance from the warm radiator which appears as a noticeable light surface in the image.

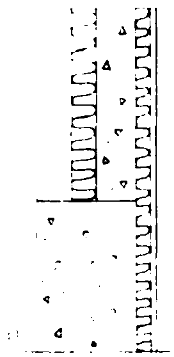




RELIABILITY OF MEASUREMENT METHOD - OUTSIDE WALL

FIGURE 39: Investigation of heat insulation capacity of outside wall portion where a suspected deficiency has been verified by opening - cracks in the construction combined with bad insulation material filling.

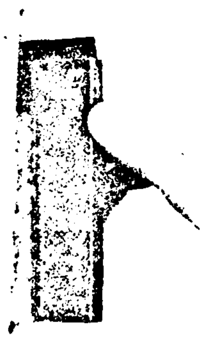


Outside wall, from the outside:

Brick facing
100 mm mineral wool
(A quality)
150 mm concrete
50 mm mineral woold
13 mm gypsum panel

inside 

115 mm concrete
250 mm light concrete
50 mm mineral wool
13 mm gypsum panel



Measuring conditions:

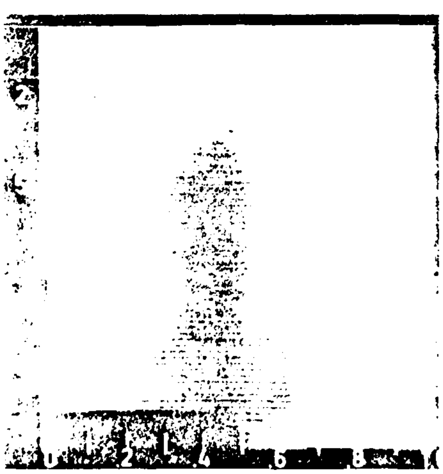
Cloud cover:
Outdoor air temperature - 4°C
Indoor air temperature: + 21°C
Wind conditions: 3 m/s (towards facade)
$p_i - p_u$: - 5 Pa

a) Construction of outside wall (horizontal section)

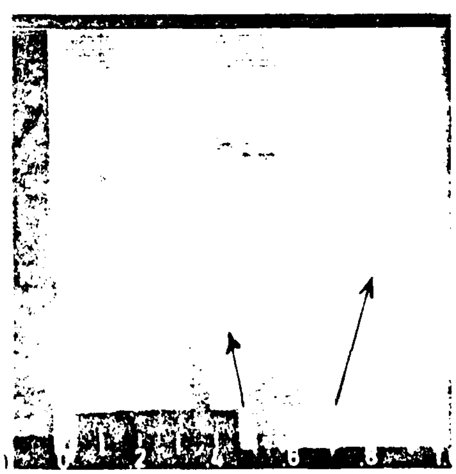
b) Opened wall portion seen from the warm side. Vertical crack between light concrete block and concrete wall, where cold outdoor air has leaked in and propagated in the construction, resulting in cooled walls.

c) Thermogram of partially cooled wall portion. The cooled area has a vertical expansion with relatively diffuse borders and corresponding to a relative great proportion of the outside wall from floor to ceiling. The cooling is related to deficiencies according to b).

d) $t_{ref}$ = + 20°C
$\Delta I$ = - 2.4 isotherm units
$\Delta t$ = 3.5 °C
v = 0 m/s




(d)

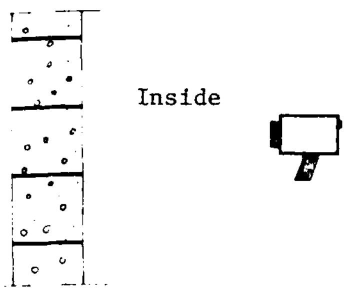


RELIABILITY OF MEASUREMENT METHOD - OUTSIDE WALL

FIGURE 40: Investigation of heat insulation capacity of outside wall of light concrete where a suspected deficiency - cracks in the construction - was verified by means of visual inspection, smoke gas test, and air speed measurement.

Outside wall, from the outside:

Facing
250 mm light concrete
Facing




a)

b)

Measurement conditions:

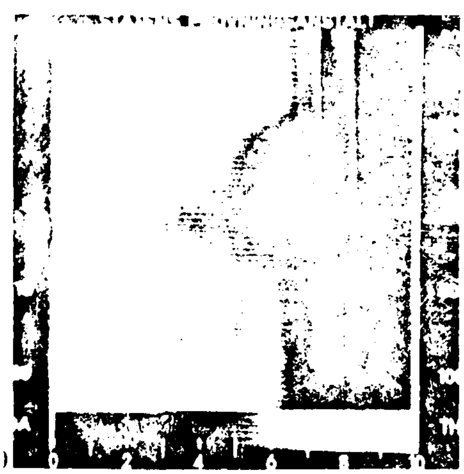
Cloud cover: Cloudy
Outdoor air temperature: + 3°C
Indoor air temperature: + 23°C
Wind conditions: Calm
$p_i - p_u$: - 20 Pa

a) Construction of outside wall.

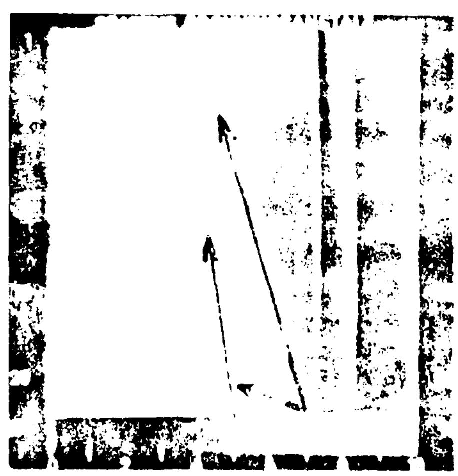
b) Cracks in outside wall portion. The crack went through the entire thickness and caused direct air leakage into the residential space.

c) Thermogram of partially cooled wall portion close to the window. There was air leakage both through cracks between joints of the light concrete blocks and through leaking joint between wall and window frame.

d) $t_{ref}$ = + 22°C
$\Delta I$ = - 1.1 isotherm unit
$\Delta t$ = 1.5°C
v = approx. 0.3 m/s (close to the wall at the crack)



c)



d)

## 4.5. Measurement of heat resistance and thermography

The heat camera offers great possibilities to undertake relatively precise investigations of the surface temperature variations on the constuction surface under certain conditions. This makes it possible to obtain an image of the heat flow and air leakage distributions.

When determining the heat resistance of the construction according to Equation 3.13., the following requirements must be fulfilled:

1. The emitting, reflecting, and transmitting characteristics of the surface are known and constant for the surface portion of interest.
2. The radiation towards the surface is known and is evenly distributed over the measurement surface.
3. There is temperature balance and stability both in the construction and in the ambient air.
4. The heat transfer resistances at the surfaces of the construction are known and constant over the surface portion in question.
5. There are no internal heat sources in the construction.
6. Relevant temperatures are measured.

In practice, there is a certain variation of the $m_i$ value along the surface of a construction, depending both on the geometrical design of the construction (corners, etc.) and on the environment where the construction is located. As a rule, exact values for $m_i$ and $m_u$ are not known, and the uncertainty of the estimated values is usually so great that it serves no purpose to measure the heat resistance of the wall with great precision. In field measurements, there is an additional factor of uncertainty, since there is usually no temperature balance in the construction of interest.

It can be stated in summary that the thermography method is qualitative[1)] and is primarily used to demonstrate variations in heat resistance and air leakage. For a quantification[2)] of the heat resistance and air tightness of a building, additional, supplementary measurements are required.

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1) Qualitative testing is testing with the purpose of determining certain conditions (whether certain characteristics can be demonstrated).

2) Quantitative testing is testing with the purpose of determining magnitudes (magnitude of characteristics). (19).

# 5. COMPARATIVE THERMOGRAMS FROM FIELD MEASUREMENTS

The type thermograms included in the building research report Thermography of buildings (12) have been produced in laboratories. Under such conditions, the possibilities were limited to prepare thermograms of, on one hand, various construction types and details, and,on the other hand, types of deficiencies that frequently occur in the practice.

The purpose of the present investigation was to supplement the earlier material with a number of cases from the practice. Here, thermograms have been taken of frequently occurring deficiencies in insulation and tightness in various types of constructions, where different materials have been used.

The purpose of comparative thermograms is to facilitate interpretation and evaluation of thermograms so that more detailed and unequivocal information can be gained from the heat images produced in thermography.

The constructions that have been selected belong to the most common ones in the country. The walls consist of light walls with stud skeleton and high quality insulation material or walls with a light concrete or concrete structure. Usually, the beam tiers consist of various types of wooden constructions with mineral wool insulation, but there are also some constructed in concrete.

The examples shown have been taken from an investigaion material covering a total of some 400 projects, corresponding to approximately 3,000 residential units in small houses and multiple dwellings, where each partial project may correspond to a small number of such units or up to several hundred.

The comparative thermograms are taken under well known conditions corresponding to the requirements that have been previously identified. Interpretation and analysis of the thermograms has taken place either by comparison with type thermograms or by means of visual inspection or supplementary measurements.

Each practical case is shown in the form of two thermograms (grey tone image and isotherm image).

The background information shows the construction drawing and a brief description of the existing defiency, if any. In conjunction with the measuring case in question, brief comments are made on the appearance of the thermogram.

The designations used correspond to those in the previous section. The auxiliary data of comparative thermograms are divided into groups according to construction component and construction type according to following:

Pp. 87-94: examples of deficiencies in insulation and tightness standard at the eaves (saddle roof, flat roofs, and "pulpit roofs"), FIG. 41 - 48.

Pp. 95-100: examples of deficiencies in insulation and tightness standards of insulated roofs, FIG. 49 - 54.

Pp. 101-103: examples of deficiencies in insulation and tightness standards in truss tiers, FIG. 55 - 57.

Pp. 104-110: examples of deficiencies in insulation and tightness standards in beam tiers, FIG. 58 - 64.

Pp. 111-115: examples of deficiencies in insulation and tightness standard at the connections of the floor joint tiers, FIG. 65 - 69.

Pp. 116-130: examples of deficiencies in insulation and tightness standard in outside walls, FIG. 70 - 84.

COMPARISON THERMOGRAM - SADDLE ROOF (truss connection)

FIGURE 41: Deficiencies in insulation and tightness at the eaves due to unsatisfactory fitting of insulation material and unsatisfactory workmanship in the wind barrier.

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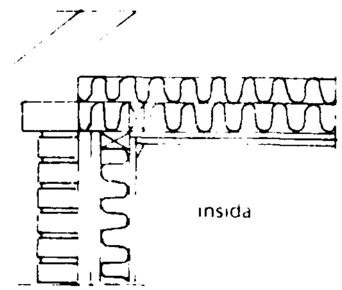
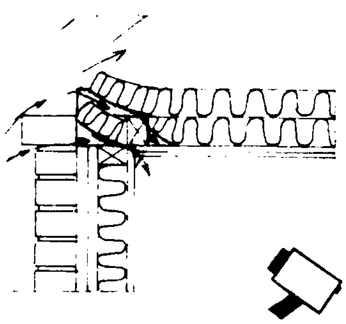
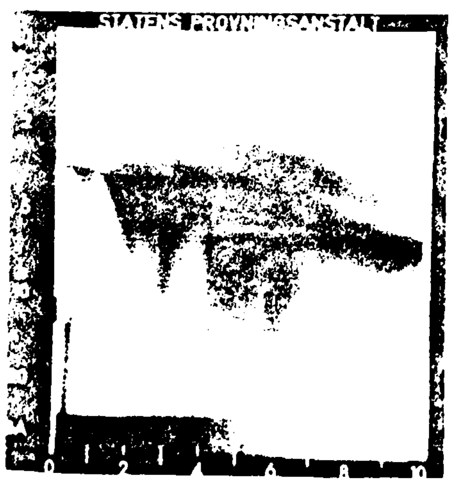
Truss, from the top:
75 + 75 mm mineral wool
(B quality)
Diffusion barrier
19 mm gypsum panel
13 mm gypsum panel



Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 7°C
Indoor air temperature: + 21°C
Wind conditions: approx. 2 m/s (perpendicular to facade)
$p_i - p_u$: - 20 Pa

a) Construction at the eaves
b) Observed deficiency in the insulation and tightness performance.
c) Thermogram of surface portion under the eaves. Cooled area has characteristic "toothy" outline, indicating inward air leakage.
d) $t_{ref}$ = + 20°C
   $\Delta I$ = - 11.6 isotherm units
   $\Delta t$ = 17°C
   v = 1.0 - 1.5 m/s (at eaves)




d)


COMPARISON THERMOGRAM - SADDLE ROOF (truss connection)

FIGURE 42: Deficiency in insulation and tightness at eaves due to insufficient insulation material filling and badly executed wind barrier.

Truss, from the top:

30 mm mineral wool mat

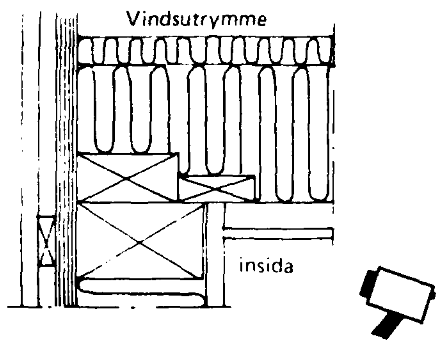
120 mm mineral wool panel

19 mm sheet screen

Polyethene (PE) foil

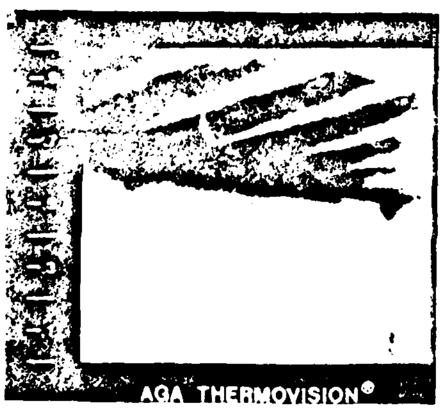
13 mm gypsum panel

a)




b)

c)

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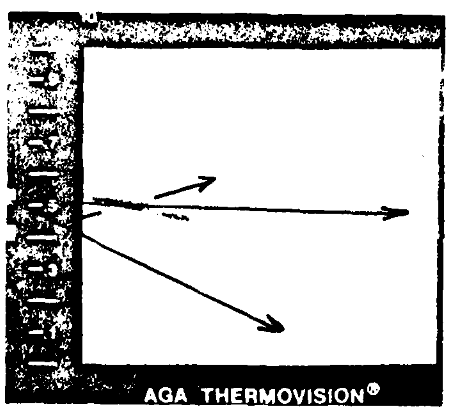



Measuring conditions:

Cloud cover: Overcast

Outdoor air temperature: + 2°C

Indoor air temperature: + 21°C

Wind conditions: 2 - 3 m/s (perpendicular to facade)

$P_i - P_u$: - 5 Pa

a) Construction at eaves

b) Observed error in the insulation executions (No PE foil installed)

c) Thermogram of surface portion at the eaves. Cooled surface portions appear as well marked dark lines, indicating inward air leakage in the channels formed in the construction by the sheet screens.

d) $t_{ref}$ = + 20°C

$\Delta I$ = - 1.1 isotherm units

$\Delta t$ = 2.0°C

v = 0 m/s

COMPARISON THERMOGRAM - FLAT ROOFS (truss connections)

FIGURE 43: Deficiency - crack formation - in the tightness at the eaves. Bad sealing between concrete beams and outside wall.

---

Truss, from above:
130 mm mineral wool
160 mm concrete
Outside wall, from outside:
Facing
75 mm light concrete
75 mm concrete
20 mm mineral wool
13 mm gypsum panel.

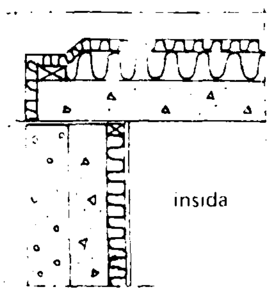
Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 30°C
Indoor air temperature: + 23°C
Wind conditions: Calm
$p_i - p_u$: - 20 Pa

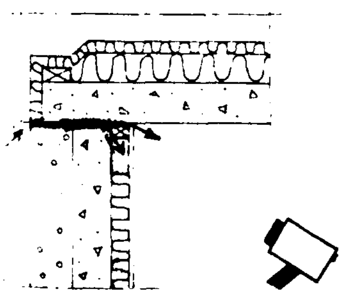
a) Construction at the eaves.

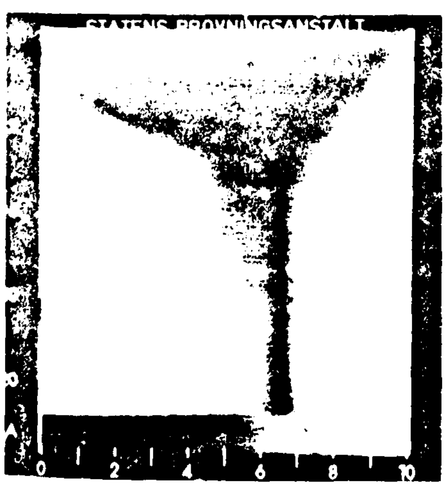
b) Observed deficiency (crack formation at the eaves).

c) Thermogram of surface portion at the eaves showing a cooled area in the roof angle. The cooling is caused by inward air leakage through a joint (crack formation).

d) $t_{ref}$ = + 22°C
$\Delta I$ = - 5.3 isotherm units
$\Delta t$ = 7.0°C
v = 1 - 3 m/s (locally at the roof angle)



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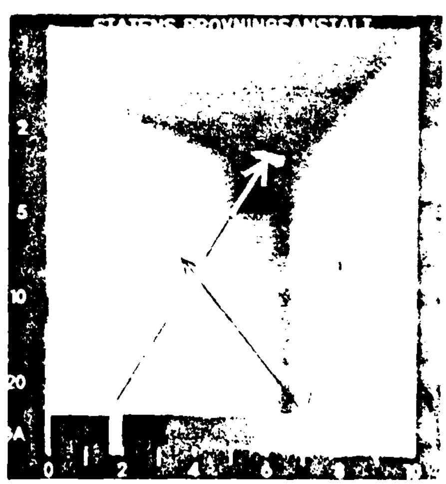
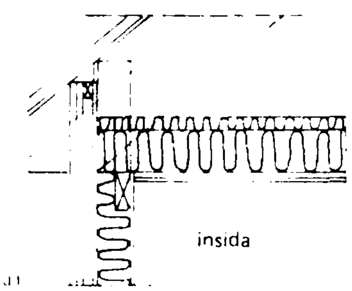


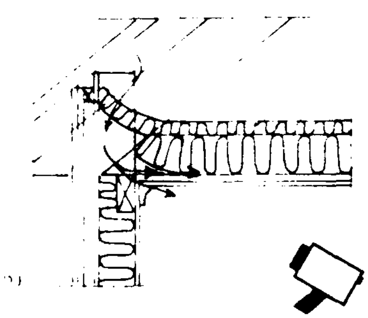
COMPARISON THERMOGRAM - SADDLE ROOF (truss connection)

FIGURE 44: Deficiencies in insulation and tightness at the eaves due to insufficient insultaion material filling in the construction and bad execution of wind barrier.

---

Truss, from above:
50 + 150 mm mineral wool
Plastic foil
19 mm sheet screen
13 mm tongue in groove wood fiber planking.



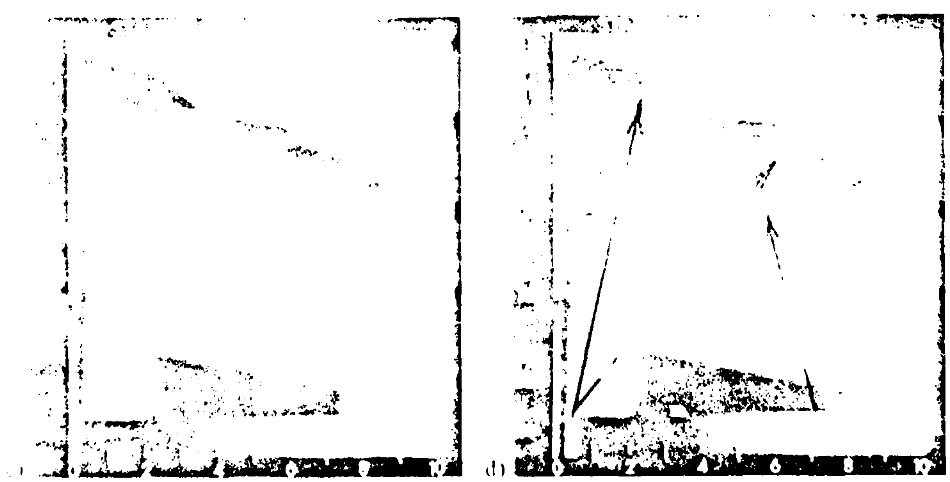
Measuring conditions:
Cloud cover: Clear
Outdoor air temperature: - 20°C
Indoor air temperature: + 19°C
Wind conditions: 1 - 2 m/s (obliquely against the facade)
$p_i - p_u$: - 7 Pa

a) Construction of the truss connection.

b) Erroneous insulation execution at eaves.

c) Thermogram of surface portion at the roof angle. The area next to the cornice is cooled. The cooling due partially to inward air leakage, partially insufficient insulation material filling at the connection.

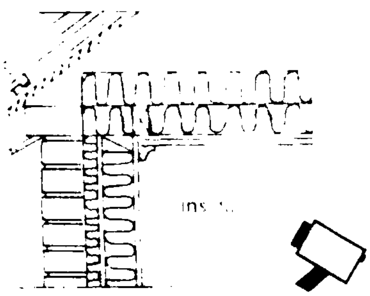
d) $t_{ref}$ = + 17°C
$\Delta I$ = - 6.8 isotherm units
$\Delta t$ = 11.0°C
v = 0.5 - 3.0 m/s



COMPARISON THERMOGRAM - SADDLE ROOF (truss connection)

FIGURE 45: Deficiencies in insulation and tightness at the truss connection due to insufiicient filling of insulation material in the construction and badly executed wind barrier.

Truss, from above:
200 mm mineral wool
19 mm sheet screen
Polyethene (PE) foil
13 mm gypsum panel



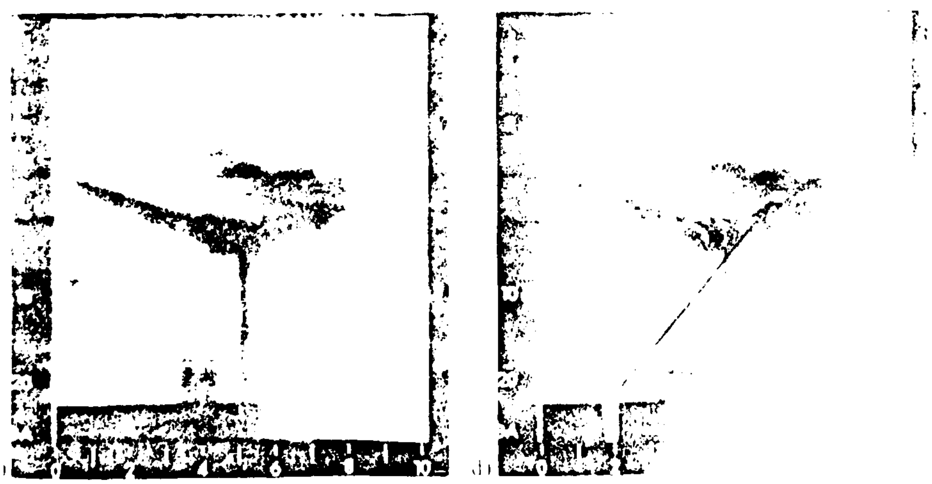
Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 2°C
Indoor air temperature: + 20°C
Wind conditions: Calm
$p_i - p_u$: - 5 Pa

a) Construction of the truss connection.

b) Inward air leakage at the eaves. Bad insulation filling aroud the rafters. No continuity of the wind barrier at the truss proper.

c) Thermogram of surface portion at the roof angle. Cooled area in the ceiling next to the roof angle is due to bad insulation around the truss at the edge of the rafters. The cooling is also propagated in the channels formed by the sheet screen construction. Certain inward air leakage into the residential area.

d) $t_{ref}$ = 19°C
$\Delta I$ = - 5.2 isotherm units
$\Delta t$ = 8.0°C



COMPARISON THERMOGRAM - SADDLE ROOF (truss connection)

FIGURE 46: Deficiency - unsatisfactory fitting of insulation material around the ventilation channels - in the insulation and tightness execution at the truss where ventilation channel penetrates.

---

Truss, from above:
50 + 150 mm mineral wool
Plastic foil
19 mm gypsum panel
13 mm tongue and groove wood fiber planking
(At passage of ventilation channel from drying cabinet)
Top left: Insulated ventilation channel. Top right: Attic. Bottom right: Preparation kitchen.

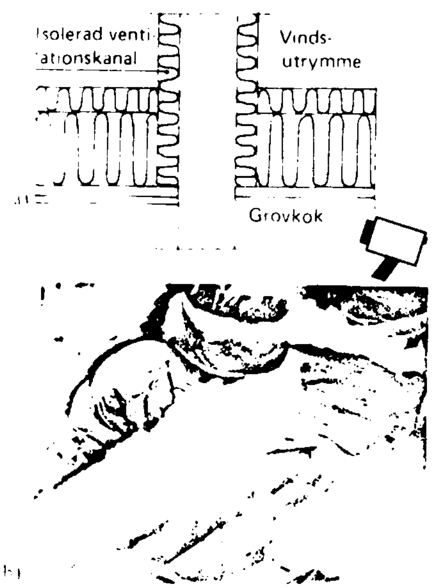
Measuring conditions:
Cloud cover: Clear
Outdoor air temperature: - 20°C
Indoor air temperature: - + 19°C
Wind conditions: 2 - 3 m/s (approx. 45° towards the facade)
$p_i - p_u$: - 7 Pa

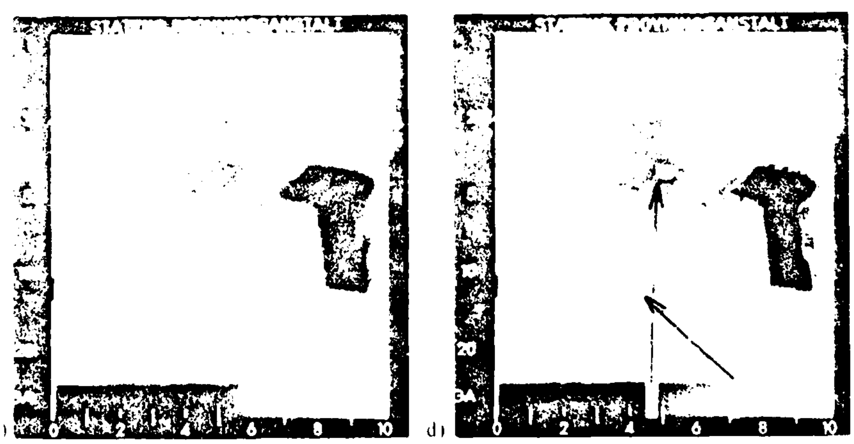
a) Truss construction and rafters at the ventilation passage.

b) Deficient insulation execution at the connection of the ventilation channel to the rafters.

c) Thermogram of surface portion at the roof with the connection of ventilation duct from drying cabinets. The surface portion is cooled due to uneven funtion of the insulation material.

d) $t_{ref}$ = + 17°C
$\Delta T$ = - 2.5 isotherm units
$\Delta t$ = 4.0°C
v = 0 m/s



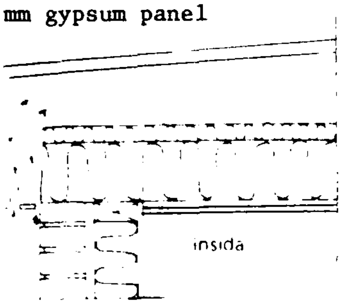



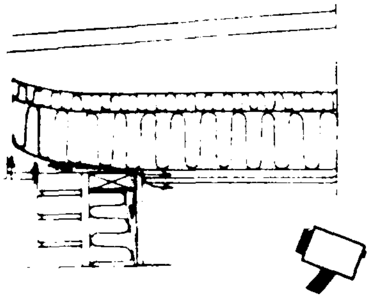
COMPARISON THERMOGRAM - FLAT ROOFS (truss connection)

FIGURE 47: Deficiency in insulation and tightness at the eaves due to unsatisfactory fitting of insulation material and badly executed wind barrier.

Roof, from above:
30 + 120 mm mineral wool
19 mm sheet screen
Diffusion barrier
13 mm gypsum panel

Wall, from outside:
Brick facing
Air space
95 mm mineral wool
Diffusion barrier
13 mm gypsum panel



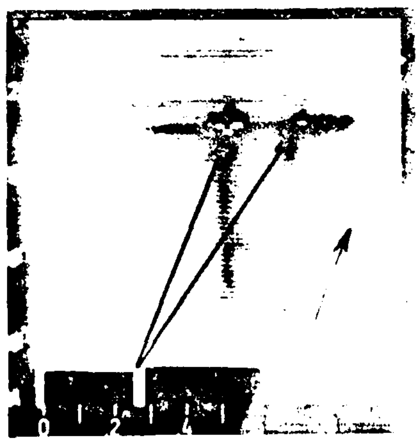
Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 4°C
Indoor air temperature: + 21°C
Wind conditions: 0.5 m/s (obliquely towards the facade)
$p_i - p_u$: - 5 Pa

a) Construction at the eaves.

b) Erroneous insulation execution in the wall and at the eaves.

c) Thermogram of surface portion at the roof angle, showing a cooled area of irregular shape. A narrow, cooled area extends downward into the wall. The cooling caused partially by inward air leakage, partially by badly executed insulation in the wall and at the eaves.

d) $t_{ref}$ = + 20°C
$\Delta I$ = - 4.5 isotherm units
$\Delta t$ = 6.5°C
v = 0.5 - 1.8 m/s (at the eaves)



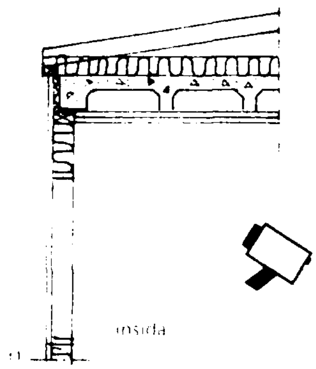
d)

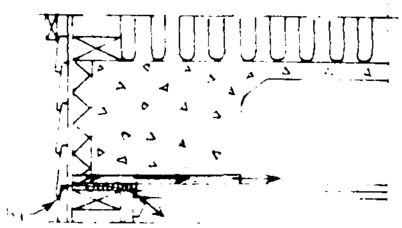
COMPARISON THERMOGRAM - PENTROOF (truss connection)

FIGURE 48: Deficiency in insulation and tightess in the truss of concrete components due to cold bridge effect and certain inward air leakage in the construction and into the residential space.

---

Truss, from above:
150 mm mineral wool
Concrete components
19 mm sheet screen
13 mm gypsum panel



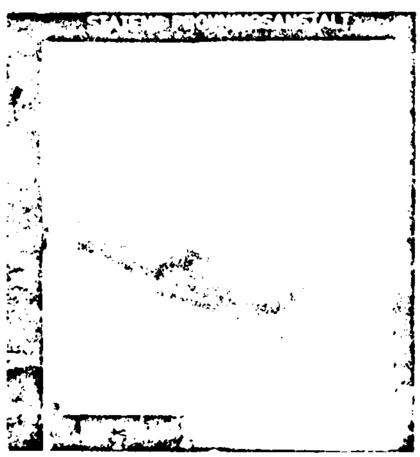
Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 3°C
Indoor air temperature L+ 23°C
Wind conditions: Calm
$p_i - p_u$: - 5 Pa

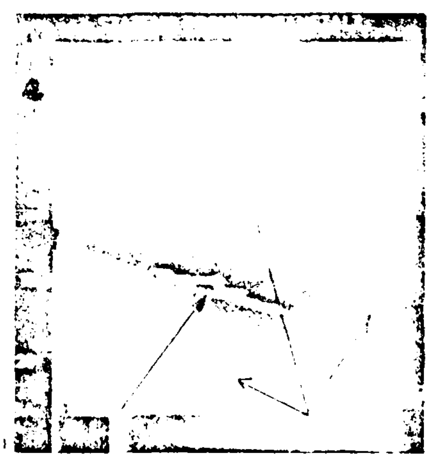
a) Construction of truss (concrete components)

b) Detail of construction cold bridge at the eaves connection.

c) Thermogram of surface portion at the roof angle A 15 - 20 cm wide strip from the roof angle forms a cooled area along the outside wall. Certain inward air leakage in the sheet screen construction, as well as lesser inward air leakage into the residential space.

d) $t_{ref}$ = + 22°C
$\Delta I$ = - 2.7 isotherm units
$\Delta t$ = 3.5°C
$v$ = 0.2 - 0.3 m/s (locally at the roof angle.





d)

COMPARISON THERMOGRAM - INSULATED ROOF (SLOPING ROOF)

FIGURE 49: Deficiency in insulation and tightness at sloping roof due to unsatisfactory fitting and attachment of insulation material towards the warm side as well as inward air leakage in the construction.

---

Sloping roof, from outside:

Outside roof construction
50 mm air space
100 + 50 mm mineral wool
19 mm sheet screen
Diffusion barrier
13 mm gypsum panel

Measuring conditions:

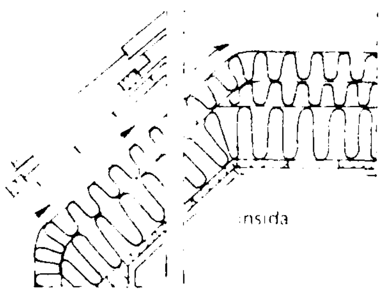
Cloud cover: Clear
Outdoor air temperature: + 2°C
Indoor air temperature: + 20°C
Wind conditions: 2 - 3 m/s (from the facade)
$p_i - p_u$: - 18 Pa

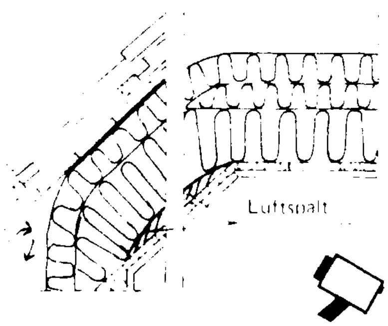
a) Construction of insulated outer roof (Below right hand part: Inside)

b) Erroneous insulation execution (Below right hand part of figure: Air space)

c) Thermogram of surface portion at the sloping roof. Inward air leakage in the construction, whereby cold air is diffused in the empty spaces between insulation material and sheet screen.

d) $t_{ref}$ = + 19°C
$\Delta I$ = - 2.6 isotherm units
$\Delta t$ = 4.0°C
v = 0 m/s

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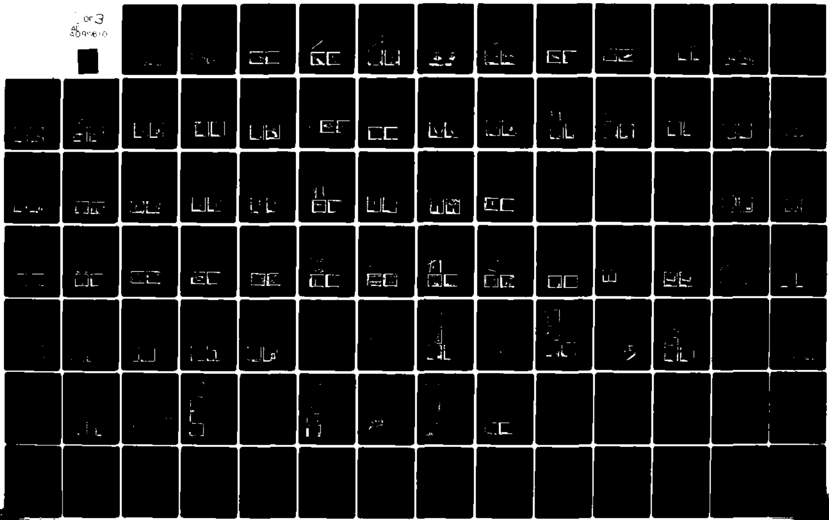
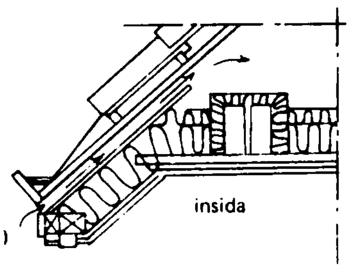


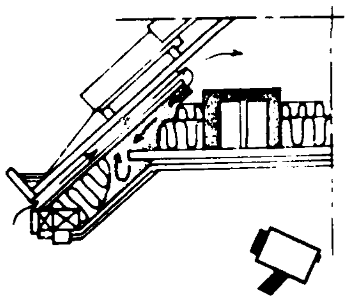
COMPARISON THERMOGRAM - INSULATED OUTSIDE ROOF (SLOPING ROOF)

FIGURE 50: Deficiency in insulation and tightness at sloping roof, due to insufficient filling of insulation material at the connection between sloping roof and collar beam.

Sloping roof, from the outside:
Outer roof construction
50 mm air space
3 mm wood fiber panel
100 mm mineral wool
19 mm sheet screen
Diffusion barrier
13 mm gypsum panel



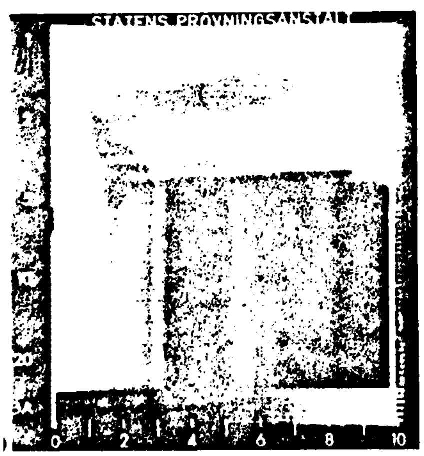

a)



b)

Measuring conditions
Cloud cover: Partially overcast
Outdoor air temperature: ± 0°C
Indoor air temperature: + 20°C
Wind conditions: 2 - 3 m/s (parallel to the facade)
$p_i - p_u$: - 4 Pa

a) Construction of insulated roof (along the facade).
b) Unsatisfactory insulation execution.
c) Thermogram of surface portion at sloping roof above window. Local cooling - insulation material not filling the space in the construction - both of parts of the roof- and of parts of the connecting truss.
d) $t_{ref}$ = + 19°C
$\Delta I$ = - 2.0 isotherm units
$\Delta t$ = 3.0°C
v = 0 m/s

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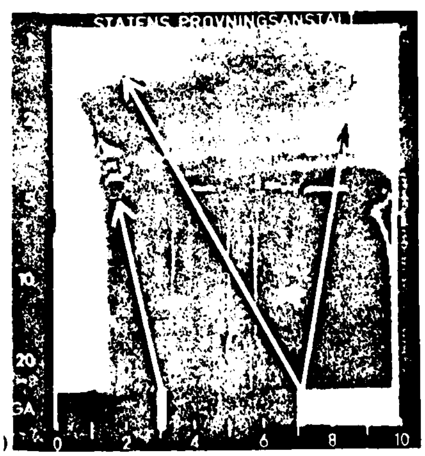
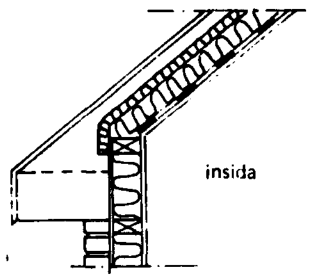


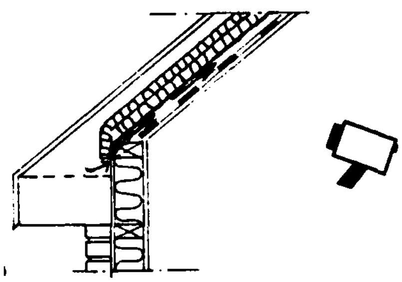

d)

COMPARISON THERMOGRAM - INSULATED OUTSIDE ROOF (SLOPING ROOF)

**FIGURE 51: Deficiency in insulation and tightness at sloping roof due to inward air leakage in the construction.**

Roof, from above:
Outer roof construction
Air space
30 + 120 mm mineral wool
19 mm sheet screen
Plastic foil
13 mm gypsum panel



Measuring conditions
Cloud cover: Overcast
Outdoor air temperature: - 3°C
Indoor air temperature: + 21°C
Wind conditions: 2 - 3 m/s (from facade)
$p_i - p_u$: - 5 Pa

a) Construction of insulated outside roof (In figure: Inside)

b) Deficient insulation execution.

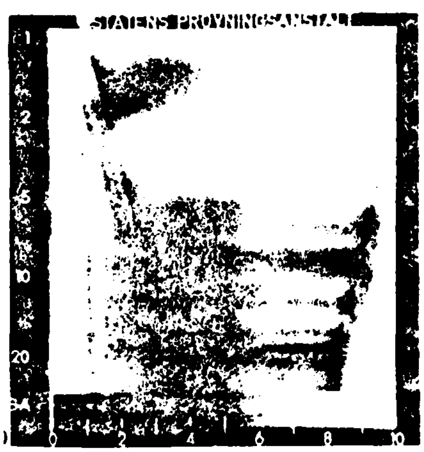
c) Thermogram of surface portion at the outer roof. The temperature is unevenly distributed over the roof surface. Cooled portions do, to some extent, indicate the channels in the sheet screen.

d) $t_{ref}$ = + 20°C

$\Delta I$ = - 2.7 isotherm units

$\Delta t$ = 3.5°C

v = 0.7 - 1.0 m/s (close to the eaves)

c)
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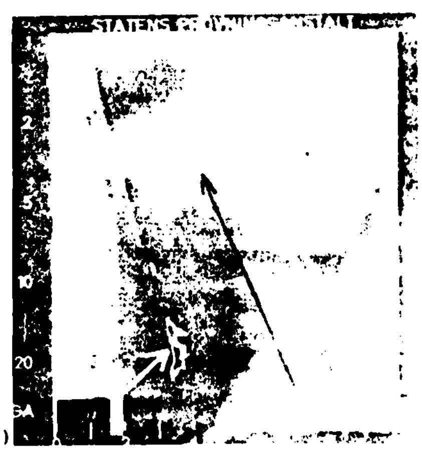
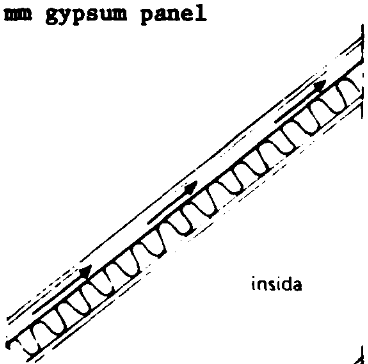


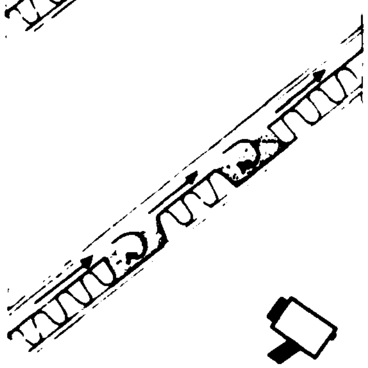
COMPARISON THERMOGRAM - INSULATED OUTSIDE ROOF

FIGURE 52: Deficiency in insulation and tightness due to insufficient filling of insulation material, in combination with inward air leakage in the construction.

Roof, from the outside:
Outer roof construction
Air space
Sheathing
100 mm mineral wool (B qual.)
Polyethene (PE) foil
13 mm gypsum panel




a)



b)

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 3°C
Indoor air temperature: + 19°C
Wind conditions: 2 - 3 m/s (obliquely towards the roof surface)
$p_i - p_u$: - 6 Pa.

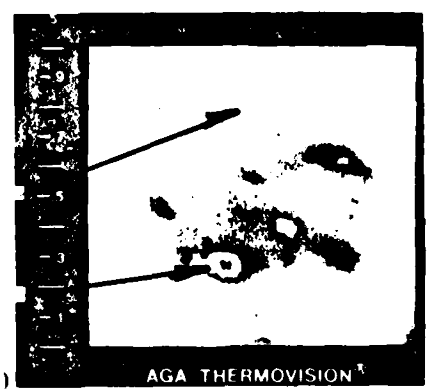
a) Construction of insulated outside roof (In figure: Inside)

b) Deficient insulation execution

c) Thermogram of surface portion of roof. Cooled areas appear as an irregular pattern over the surface. The cooling is related to bad filling of insulation material in combination with convective air movements in the construction.

d) $t_{ref}$ = + 18°C
$\Delta I$ = - 1.7 isotherm units
$\Delta t$ = 3.0°C
v = 0 m/s


c)




d)

COMPARISON THERMOGRAM - INSULATED OUTSIDE ROOF

FIGURE 53: Deficiencies in insulation execution, partial elimination of insulation material.

Roof, from the outside:

Outside roof construction

Air space

Sheathing

120 mm mineral wool

Polyethene (PE) foil

13 mm gypsum panel

Measuring conditions:

Cloud cover: Overcast

Outdoor air temperature: + 3°C

Indoor air temperature: + 19°C

Wind conditions: 2 - 3 m/s (obliquely against the roof surface)

$p_i - p_u$: - 6 Pa.

a) Construction of outside roof (Inside figure: Inside)

b) Deficient insulation execution. The thickness of the insulation is reduced to approx. 50% of original thickness.

c) Thermogram of cooled surface portion in the roof. The cooled area is well marked with even outlines. The cooling is caused by approx. 50% insulation material is missing in the spaces between the beams according to b).

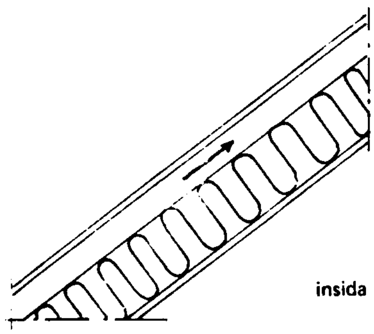
d) $t_{ref}$ = + 18°C

$\Delta I$ = - 1.5 isotherm units

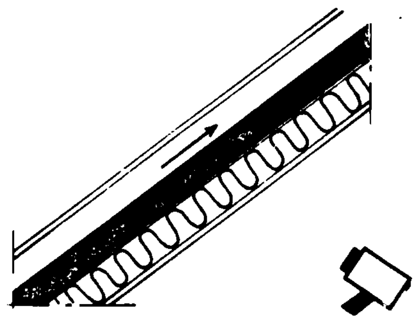
$\Delta t$ = 2.5°C

v = 0 m/s

a)




b)



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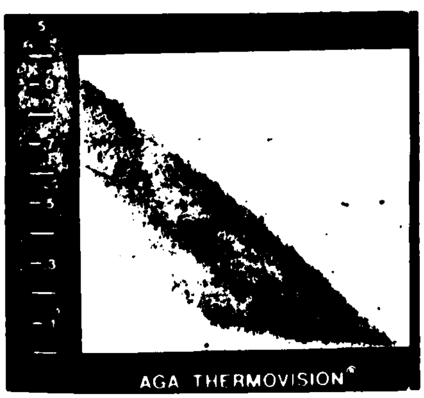


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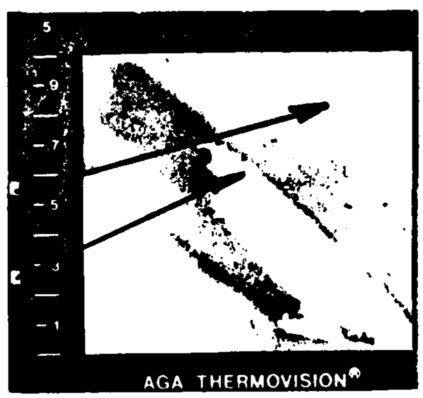
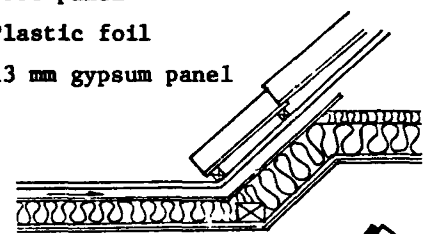


COMPARISON THERMOGRAM - INSULATED OUTSIDE ROOF OF WOOD (connection to windows)

FIGURE 54: Deficiency in insulation and tightness due to bad fitting of insulation material against studs and badly executed wind barrier.

Roof portion from outside:
Brick roofing
Sheathing paper
Wood panel
Air space
3 mm wood fiber panel
100 mm mineral wool
Wood panel
Plastic foil
13 mm gypsum panel


a)

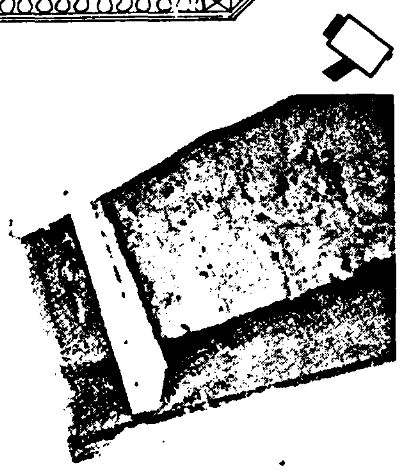
Measuring conditions:
Cloud cover: Clear
Outdoor air temperature: ± 0°C
Indoor air temperature: + 20°C
Wind conditions: 2 - 3 m/s (parallel with roof)
$p_i - p_u$: - 4 Pa

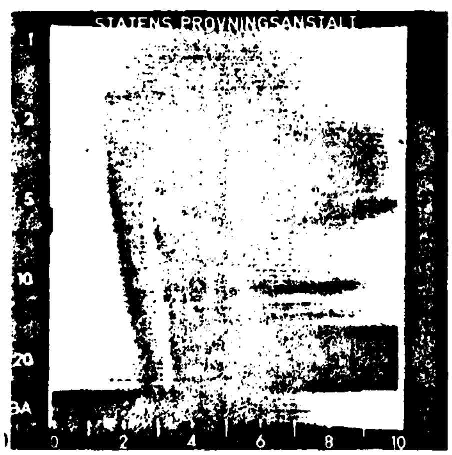
a) Outside roof construction at bay window.

b) Open wall portion from the inside. The insulation is badly fitted against the studs and does not touch the wall material on the warm side. Air space, approx. 5 cm.

c) Thermogram of surface portion at sloping roof showing cooled surface portions. The cooling caused by air penetrating into the construction in the space insufficiently filled with mineral wool.

d) $t_{ref}$ = + 19°C
$\Delta$ I = - 2.0 isotherm units
$\Delta$ t = 3.0°C
v = 0 m/s


b)



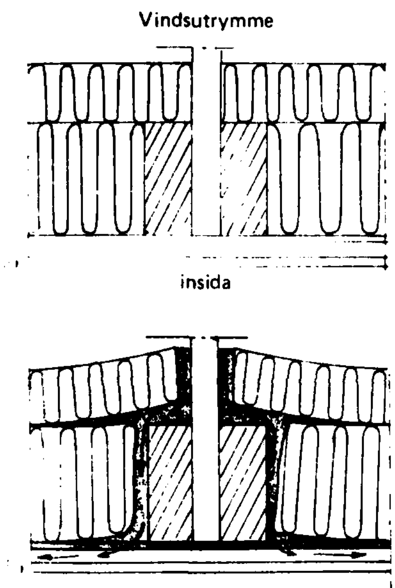
c)

d)

COMPARISON THERMOGRAM: HORIZONTAL TIER OF ROOFING BEAMS

**FIGURE 55**: Deficiency in insultaion and tightness due to bad filling of insulation material against the construction components, in combination with inward air leakage.

Beam tier, from above:
70 + 150 mm mineral wool
19 mm sheet screen
Plastic foil
13 mm gypsum panel



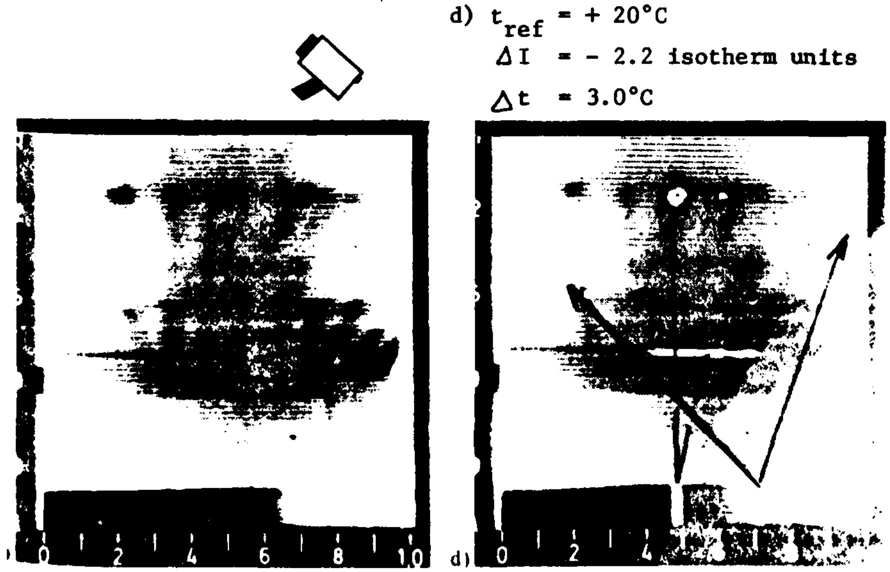

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 4°C
Indoor air temperature: + 21°C
Wind conditions: 0.5 m/s (perpendicular to eaves)
$p_i - p_u$: - 5 Pa

a) Construction of roof beam tier. In order for insulation to function well, careful fitting of the mineral wool against the truss is required. (Above figure: Attic space. Below figure: Inside)

b) Unsatisfactory filling of insulation material. Outside air propagates in empty spaces and channels formed in sheet screen construction. The plastic foil should be placed in the layer between the sheet screen and the insulation.

c) Thermogram of surface portion at roof and roof angle. Cooled aeea in the roof appears as dark parallel lines starting from the rafters.

d) $t_{ref}$ = + 20°C
$\Delta I$ = - 2.2 isotherm units
$\Delta t$ = 3.0°C



COMPARISON THERMOGRAM - HORIZONTAL TIER OF ROOFING BEAMS

FIGURE 56: Deficiency in insulation and tightness due to bad insulation around electrical wirings in the construction.

Beam tier, from above:
30 + 120 mm mineral wool
(B quality)
Electrical wiring
19 mm sheet screen
Diffusion barrier
13 mm gypsum panel

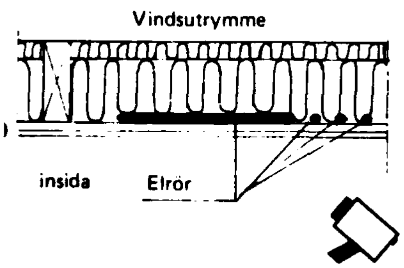
Measuring conditions
Cloud cover: Overcast
Outdoor air temperature: - 4°C
Indoor air temperature
Wind conditions: 0.5 - 1.0 m/s (perpendicular towards the facade)
$p_i - p_u$: - 5 Pa

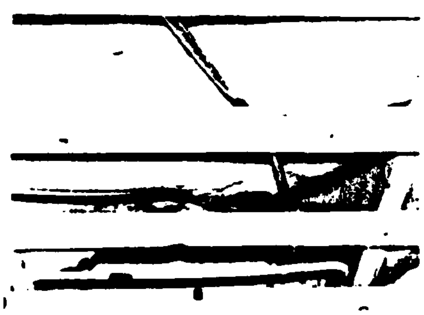
a) Construction of roof beam tier (Above figure: Attic space. Below figure: Inside / Electrical wiring conduits)

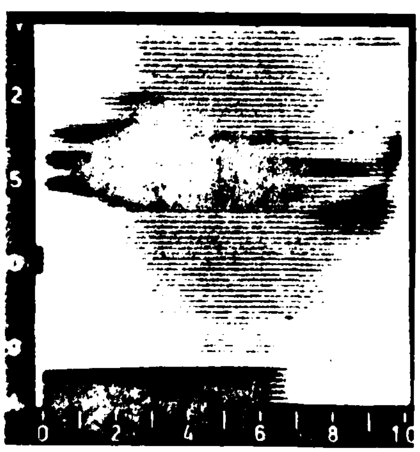
b) Deficient insulation around electrical wiring conduit.

c) Thermogram of surface portion in roof, showing a relatively obviously cooled portion. The cooling caused by unsatisfactory execution of insulation around electrical wiring conduits. Cooled areas propagate from the rafters.

d) $t_{ref}$ = + 20°C
$\Delta I$ = - 5.1 isotherm units
$\Delta t$ = 7.5°C
v = 0 m/s

a)



b)


c)


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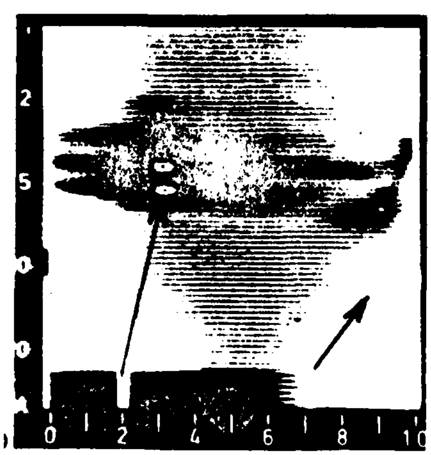
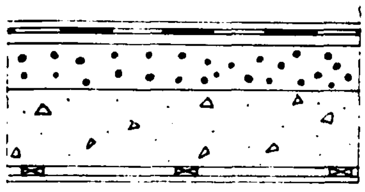
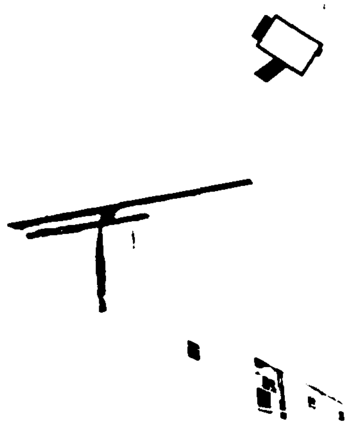


COMPARISON THERMOGRAM - ROOF TRUSS CONSTRUCTION OF LIGHT CONCRETE

FIGURE 57: Deficiency in roof beam tier due to moisture leakage into the construction.

Roof, from the outside:
Roof covering
40 mm concrete
150 - 200 mm light clinker
300 mm concrete
25 mm wood panel



Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 4°C
Indoor air temperature: + 16°C
Wind conditions: Calm
$p_i - p_u$: - 2 Pa

a) Roof construction (Under figure: Inside)

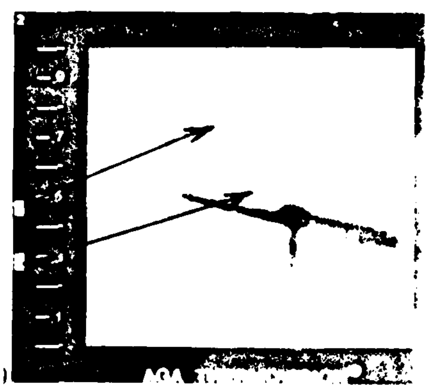
b) Roof portion, where part of the wood panel has been removed. The surface of the wood panel was dry on the measuring occasion. However, both concrete and sheathing were moist due to inward water leakage in the untight construction.

c) Thermogram of roof portion showing a cooled area. The cooling is due to moisture damage.

d) $t_{ref}$ = + 16°C
$\Delta I$ = - 0.4 isotherm units
$\Delta t$ = 0.5°C
$v$ = 0 m/s

c)

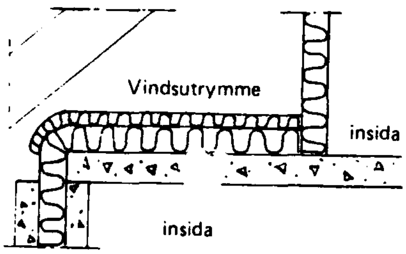


d)


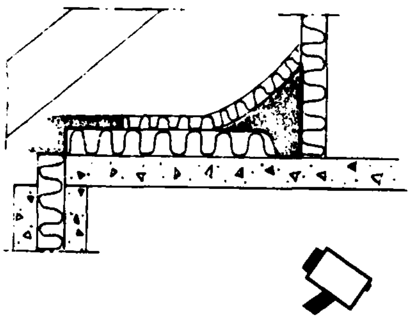
COMPARISON THERMOGRAM - INTERMEDIATE BEAM TIERS OF CONCRETE

**FIGURE 58:** Deficiency in insulation and tightness at the connection of the intermediate beam tier to upright member wall, due to insufficient filling of insulation material and badly executed wind protection.

Beam tier from above:
50 mm mineral wool mat with superimposed heavy paper
100 mm mineral wool felt
100 and 120 mm concrete (poured on the site)



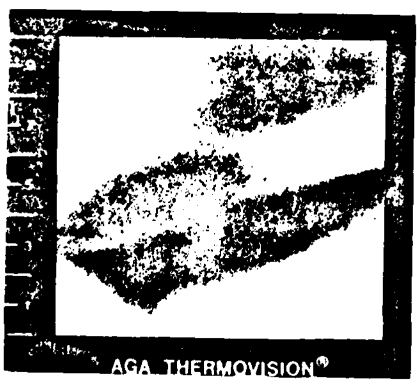

a)



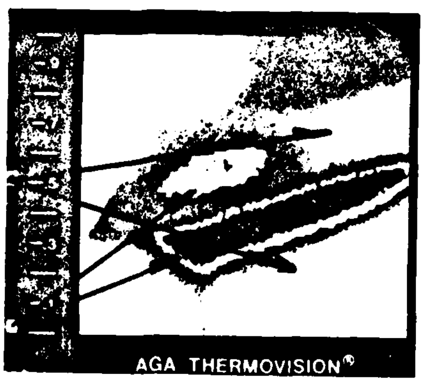
b)

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 3°C
Indoor air temperature: + 18°C
Winc conditions: 2 - 3 m/s (towards the facade)
$p_i - p_u$: - 6 Pa

a) Construction of intermediate beam tier of concrete with additional insulation of mineral wool (In figure, clockwise: Attic space / Inside / Inside).
b) Deficiency in insulation execution.
c) Thermogram of surface portion in the roof and at the roof angle. The cooling in the roof caused by insufficient filling of insulation material at the beam tier, both where the upper floor upright member wall connects to the beam and at the eaves.
d) $t_{ref}$ = + 17°C
$\Delta I$ = - 1.0 isotherm units
$\Delta t$ = 1.5°C
v = 0 m/s




c)




d)

COMPARISON THERMOGRAM - INTERMEDIATE BEAM TIER OF WOOD

FIGURE 59: Deficiency in insulation and tightness in intermediate beam tier of wood, due to insufficient filling of insulation material at connection to upright member wall.

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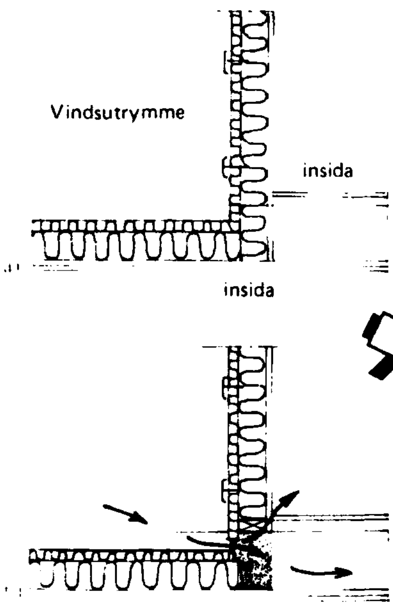
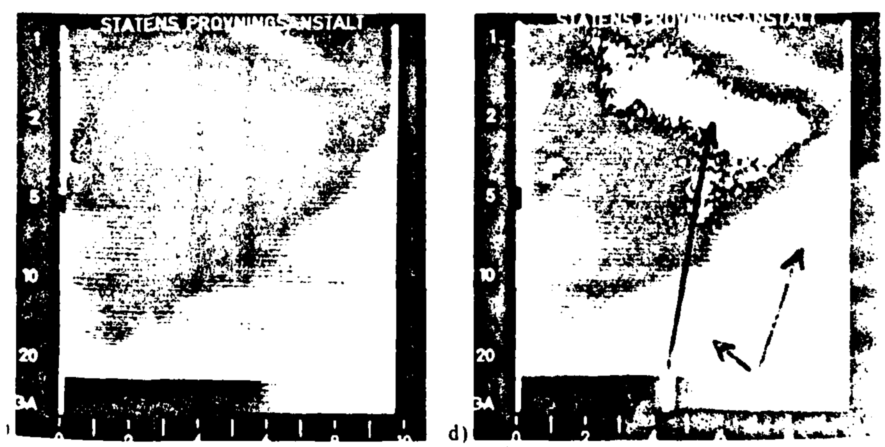
Beam tier, from above:
30 + 120 mm mineral wool
Polyethene (PE) foil
Tongue in groove
13 mm gypsum panel

Upright member wall, from outside:
Sheathing paper
30 + 100 mm mineral wool
Polyethene (PE) foil
13 mm gypsum panel

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 0.5°C
Indoor air temperature: + 22°C
Wind conditions: 1 - 2 m/s (towards facade)
$p_i - p_u$: - 5 Pa

a) Construction of intermediate beam tier and connecting upright member wall. Clockwise in figure: Attic space / Inside / Inside).
b) Deficiency in insulation and tightness.
c) Thermogram of surface portion in roof. Left portion of the roof is cooled most. The cooling caused by air leakage into the beam tier as shown in b).
d) $t_{ref}$ = + 21°C
$\Delta I$ = - 1.4 isotherm units
$\Delta t$ = 2.0°C
$v$ = 0 m/s

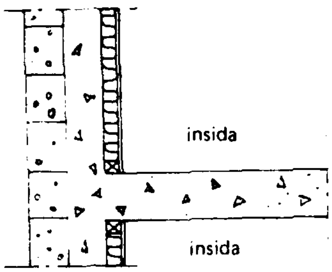


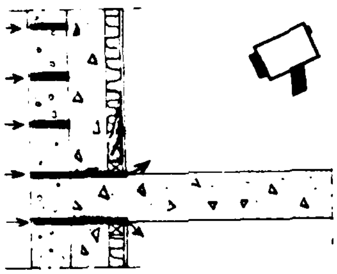
COMPARISON THERMOGRAM - INTERMEDIATE BEAM TIER OF CONCRETE

FIGURE 60: Deficiency - crack formation - in insulation and tightness due to insufficient filling of insulation material in the wall, in combination with inward air leakage in joint due to unsatisfactory connection between beam tier and outside walls.

Outside wall, from outside:
150 mm light concrete
150 mm concrete
50 mm mineral wool
50 x 50 mm studs, c max. 600 mm
13 mm gypsum panel, with aluminum foil.



a)


b)

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 1°C
Indoor air temperature: + 23°C
Wind conditions: Calm
$p_i - p_u$: - 20 Pa

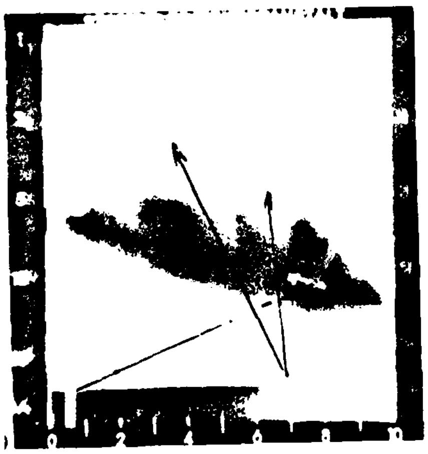
a) Construction of intermediate beam tier with connection to outside wall (In figure: Inside / Inside)

b) Inward air leakage at connection of intermediate beam tier with gable wall.

c) Thermogram of surface portion at floor angle (upper floor). Cooled areas have relatively uneven outlines. Cooling caused by inward air leakage due to untight connection of the beam tier.

d) $t_{ref}$ = + 22 °C
$\Delta I$ = - 3.3 isotherm units
$\Delta t$ = 5.0°C
v = 1 - 3 m/s

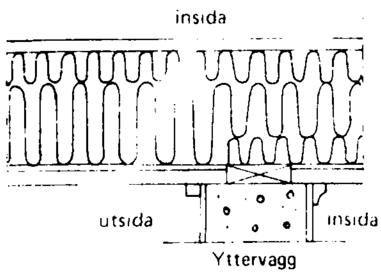

c)

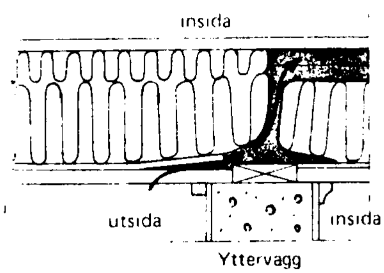

d)

COMPARISON THERMOGRAM - CORBELLED-OUT INTERMEDIATE BEAM TIER OF WOOD

FIGURE 61: Deficiency in insulation and tightness due to insufficient filling of insulation material in the beam tier at the connection to ouside wall.

Beam tier, from above:
22 mm parquet floor
Plastic foil
220 mm mineral wool
13 mm asphalt impregnated wood fiber panel
25 mm tongue-in groove panel



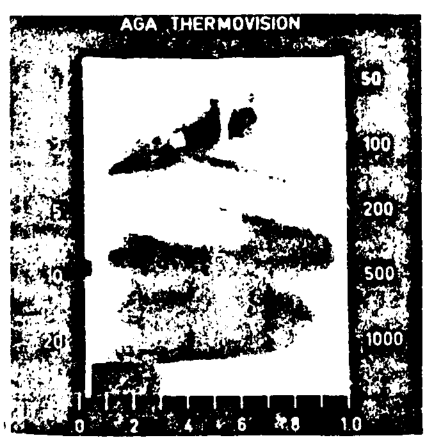

Measuring conditions:
Cloud cover: Clear
Outdoor air temperature: - 7°C
Indoor air temperature: + 22°C
Wind conditions; 2 - 3 m/s (towards facade)
$p_i - p_u$: - 4 Pa

a) Construction of intermediate beam tier with connection to outside wall (Clockwise in figure: Inside / Inside / Outside wall / Inside).

b) Deficient insulation execution at intermediate beam tier. (Inside figure - see a)).

c) Thermogram of surface portion at floor. Cooled surface portions with uneven outlines. Cooled surfaces mostly located at connection towards inwardly moved outside wall on lower floor. Inward air leakage in the beam tier.

d) $t_{ref}$ = + 21°C
$\Delta I$ = - 2.2 isotherm units
$\Delta t$ = 3.5°C
v = 0 m/s

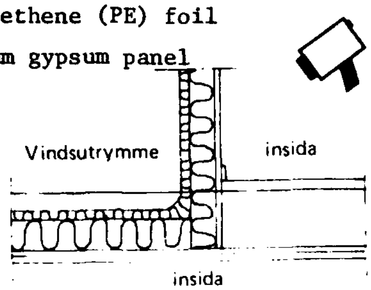



d)

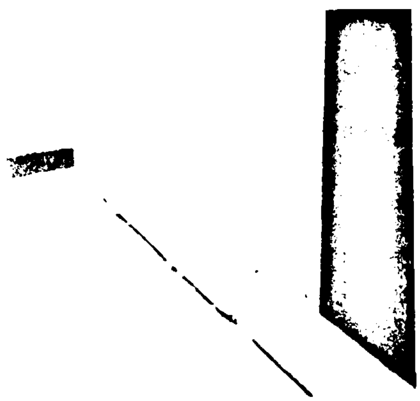
COMPARISON THERMOGRAM - INTERMEDIATE BEAM TIER OF WOOD

FIGURE 62: Deficiency in insulation and tightness due to bad sealing layer at the connection of the beam tier with upright member wall.

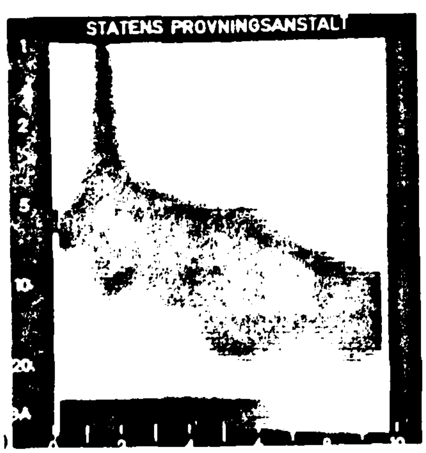
Beam tier, from above:
30 + 120 mm mineral wool
Polyethene (PE) foil
Tongue in groove
Wall, from the outside:
30 mm mineral wool mat
100 mm mineral wool
Polyethene (PE) foil
13 mm gypsum panel




a)



b)




c)


d)

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 0.5°C
Indoor air temperature: + 23°C
Wind conditions: 1 - 2 m/s (towards facade)
$p_i - p_u$: - 5 Pa

a) Construction of intermediate beam tier and connecting upright member wall (Clockwise in figure: Attic space / Inside / Inside)

b) Wall portion (partially opened wall) with kickboard removed. Inside wall covering ends closely above the floor.

c) Thermogram of cooled surface portion at the floor angle. Cooling caused by badly executed sealing at the connection between upright member wall and beam tier, resulting in strong inward air leakage.

d) $t_{ref}$ = + 22°C
$\Delta I$ = - 4.0 isotherm units
$\Delta t$ = 5.5°C
v = 3.0 m/s

COMPARISON THERMOGRAM - VENTILATION DUCT PENETRATION IN BEAM TIER

<u>FIGURE 63</u>: Deficiency in insulation due to incomplete filling of insulation material and bad sealing around vertical ventilation ducts.

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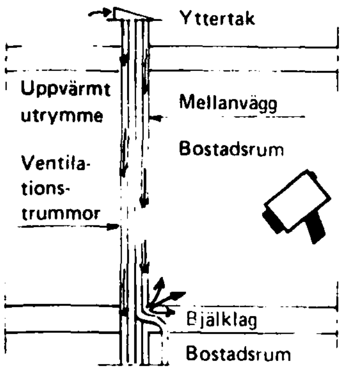
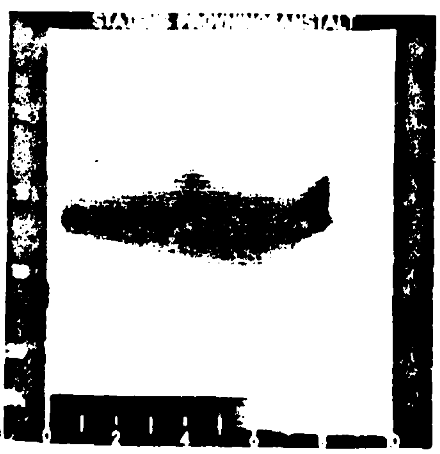
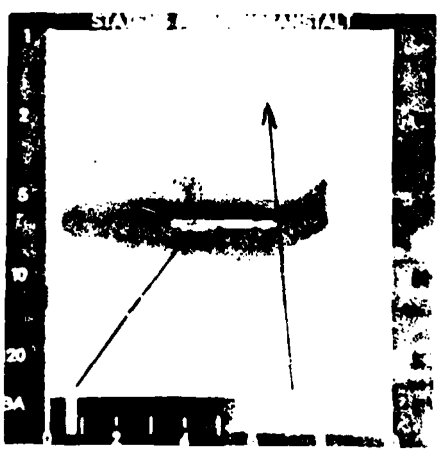
Clockwise from top in figure: Ourside roof / Intermediate wall, residential room / Beam tier / Residential room / Ventilation ducts / Heated space.




a)

b)





d)

Measuring conditions:

Cloud cover: Clear

Outdoor air temperature: - 7°C

Indoor air temperature: + 22°C

Wind conditions: 2 - 3 m/s

$p_i - p_u$: - 4 Pa

a) Location of insulated ventialtion ducts according to sketch.

b) Deficient insulation execution around the ventilation ducts with significant air space between the ducts.

c) Thermogram of cooled surface portion at floor angle where inside wall connects to intermediate beam tier. (Heated space behind the construction components.) Cooling caused by inward air leakage of cold air between the ventilation ducts. Air spreads in the beam tier, predominatly to portions where the ventilation duct connects to the beam tier, and leaks into the room.

d) $t_{ref}$ = + 22°C

$\Delta I$ = - 7.4 isotherm units

$\Delta t$ = 10.5°C

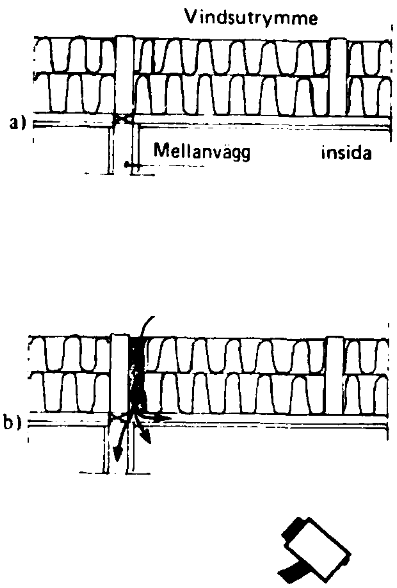
v = 2.0 - 5.0 m/s (at the floor angle)

COMPARISON THERMIGRAM - HORIZONTAL INTERMEDIATE BEAM TIER

FIGURE 64: Deficiency in insulation and tightness - bad fitting and joining of insulation material against construction components.

Beam tier, from above:
150 mm mineral wool
Polyethene (PE) foil
19 mm sheet screen
13 mm gypsum panel

Top of figure below: Attic space. Bottom of figure: Inside wall (l) Inside (r)



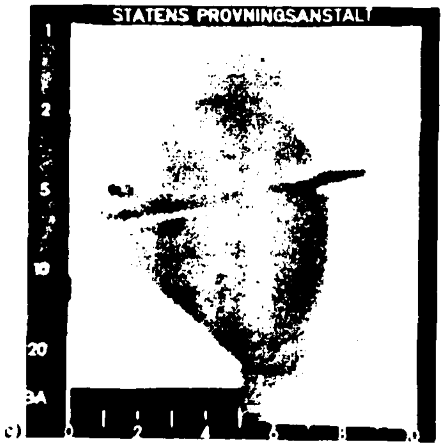

Measuring conditions:
Cloud cover: Clear
Outdoor air temperature: + 19°C
Indoor air temperature: + 20°C
Wind conditions: 1 - 2 m/s (towards facade)
$p_i - p_u$: - 5 Pa

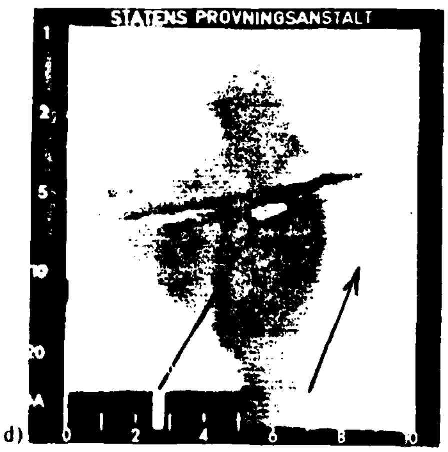
a) Construction of intermediate beam tier and its connection to inside wall.

b) Deficient insulation. The mineral wool does not touch the rafter. Air leakage into the construction.

c) Thermogram of surface portion at the ceiling angle where inside wall connects with intermediate beam tier. Cooled surfaces appear both in the ceiling and on the wall. The cold air spreads both in the inside wall and in the beam tier.

d) $t_{ref}$ = + 19°C
$\Delta I$ = - 4.5 isotherm units
$\Delta t$ = 6.5°C
v = 0.2 - 0.5 m/s (air leakage into room)

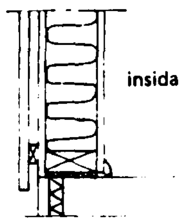


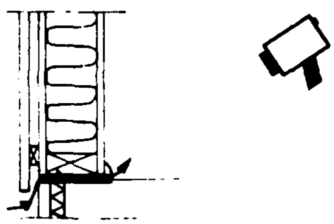
COMPARISON THERMOGRAM - FLOOR JOIST TIER OF CONCRETE AT CRAWL SPACE (connection to outside wall of wood).

FIGURE 65: Deficiency in insulation and tightness due to bad sealing of joists.

Outside wall, from outside:
Panel
Air space
Asphalt impregnated wood fiber panel
100 mm mineral wool
13 mm gypsum panel

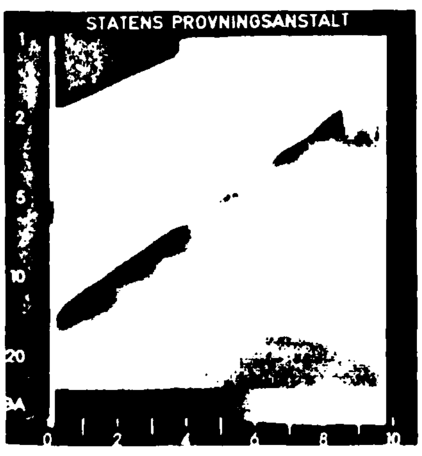


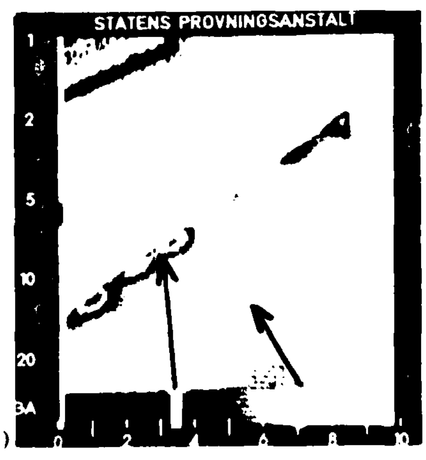
a)


b)

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 1°C
Indoor air temperature: + 23°C
Wind conditions: 1 - 2 m/s (towards facade)
$p_i - p_u$: - 5 Pa

a) Construction at the outside wall connection with the floor joist tier (In figure: Inside)
b) Deficient sealing execution at joist.
c) Thermogram of surface portion at floor angle below window portion with electrical heating panels. Uneven cooling along the kickboard. Cooling due to inward air leakage through badly sealed connection at joist as in b).
d) $t_{ref}$ = + 22°C
$\Delta I$ = - 1.9 isotherm units
$\Delta t$ = 3.5°C
$v$ = 0.5 - 1.5 m/s (at floor angle)

c) 

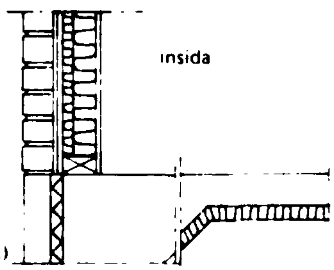

d) 

COMPARISON THERMOGRAM - FLOOR JOIST TIER OF CONCRETE, SLAB CONSTRUCTION (connection with outside wall)

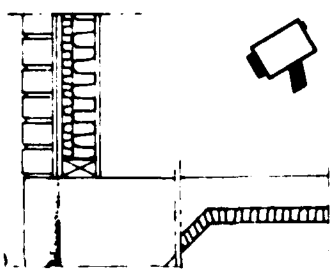
FIGURE 66: Deficiencies in insulation and tightness due to bad edge insulation.

Wall, from outside:
Brick facing
19 mm asphalt board
30 mm mineral wool panel
90 mm mineral wool panel
Diffusion-proof board
13 mm particle board

Joist tier, from above:
120 mm concrete
50 mm mineral wool




a)



b)

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 1°C
Indoor air temperature: + 20°C
Wind conditions: 3 - 5 m/s (towards facade)
$p_i - p_u$: - 5 Pa

a) Construction of joist tier and outside wall (In figure: Inside)

b) Erroneous execution of joist tier construction (edge insulation ignored).

c) Thermogram of cooled floor portion next to outside wall. Cooling appeared some 0.5 m from outside wall, caused by absence of insulation of the edge joist.

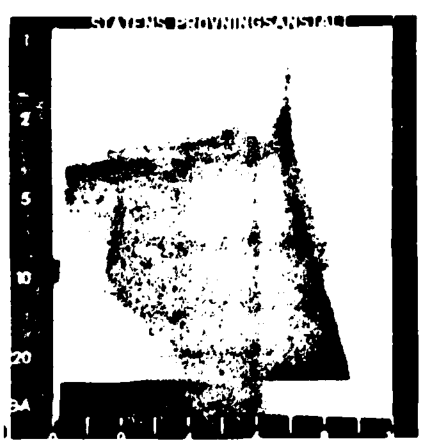
d) $t_{ref}$ = + 19°C

$\Delta I$ = - 3.1 isotherm units

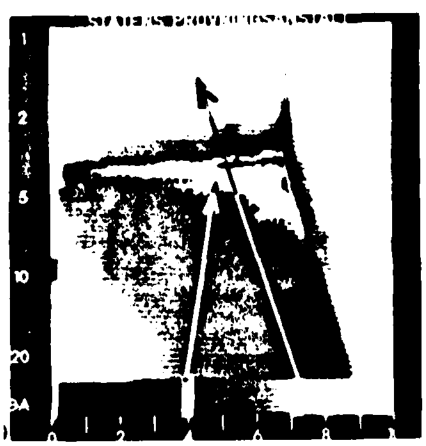
$\Delta t$ = 4.5°C

v = 0/ms

c)



d)



**COMPARISON THERMOGRAM - JOIST TIER OF WOOD AT CRAWL SPACE (connection with outside wall).**

**FIGURE 67: Deficiency in insulation and tightness due to faulty assembly and incomplete filling with insulation material in the edge portion of the joist tier.**

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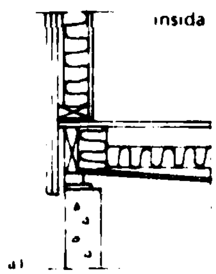
**Outside wall, from outside:**
**Wood siding**
**Air space**
**Asphalt impregnated wood fiber panel**
**95 mm mineral wool**
**13 mm gypsum panel**

**Joist tier, from above:**
**Floor covering**
**70 mm air space**
**70 mm mineral wool**
**Tongue and groove**

Measuring conditions:
Cloud cover:
Outdoor air temperature: $\pm$ 0°C
Indoor air temperature: + 21°C
Wind conditions: 2 - 3 m/s
$p_i - p_u$: - 7 Pa

a) Construction of joist tier (In figure: Inside)
b) Faulty insulation in joist tier where insulation material does not fill completely along the edge of the joist tier.
c) Thermogram of cooled surface portion at the floor angle (corner of outside walls). Cooling caused by inward air leakage both in the joist tier and into the residential area.
d) $t_{ref}$ = + 20°C
$\Delta I$ = - 1.8 isotherm units
$\Delta t$ = 3.0°C
v = 1.0 - 1.5 m/s



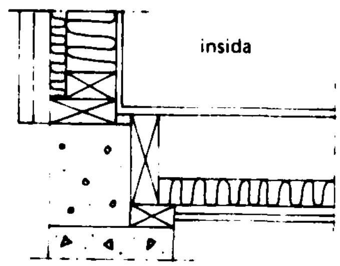

**COMPARISON THERMOGRAM - JOIST TIER OF WOOD AT CRAWL SPACE (connection with outside wall)**

**FIGURE 68:** Deficiencies in insulation and tightness due to incomplete filling of insulation material, resulting in inward air leakage into the construction,

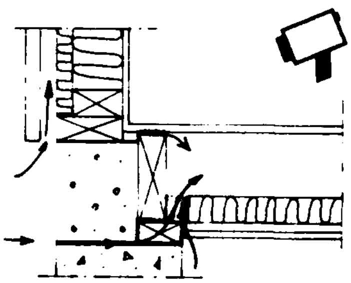
Outside wall, from outside:
Outside wall construction
30 mm mineral wool
95 mm mineral wool

Joist tier, from above:

20 mm floor covering
125 mm air space
50 mm mineral wool




a)



b)

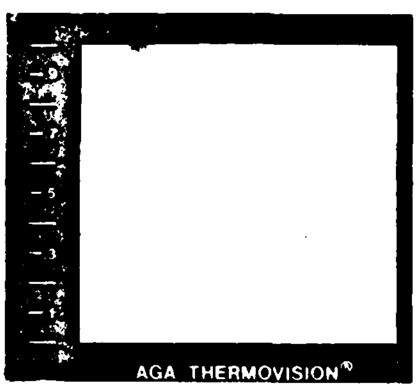
Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 2°C
Indoor air temperature: + 20°C
Wind conditions: 2 - 5 m/s (towards facade)
$p_1 - p_2$: - 5 Pa

a) Construction of wooden joist tier (In figure: Inside)

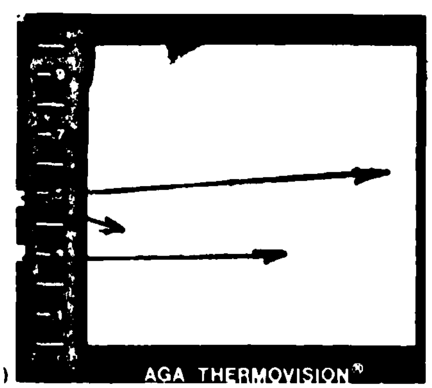
b) Faulty execution of insulation and tightness in the joist tier.

c) Thermogram of surface portion at the floor. Cooled zone on the floor. Cooling caused by air leakage into the joist tier.

d) $t_{ref}$ = + 19°C
$\Delta I$ = - 0.4 isotherm units
$\Delta t$ = 0.5°C
v = 0 m/s




c)

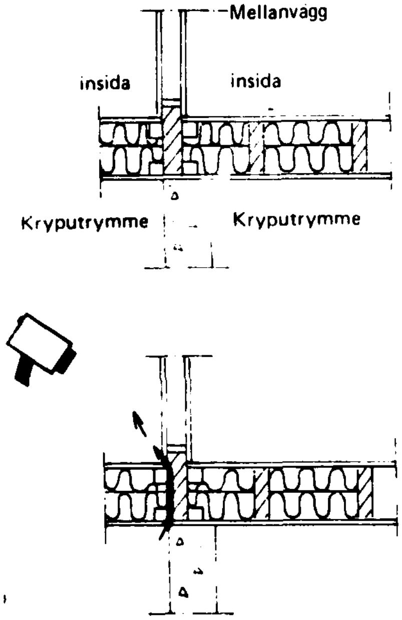



d)

COMPARISON THERMOGRAM - JOIST TIER OF WOOD AT CRAWL SPACE (connection with load carrying inside walls).

FIGURE 69: Deficiencies of insulation and tightness due to leakage in the connection between joist tier and inside wall.

Joist tier, from above:
19 mm wood fiber board
Floor joists, 50 x 200 mm
70 + 80 mm mineral wool
Cardboard
10 mm wood fiber board




Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 5°C
Indoor air temperature: + 22°C
Wind conditions: 1 - 5 m/s (towards facade)
$p_i - p_u$: - 5 Pa

a) Construction of joist tier (prefabricated components) and the inside wall connection. Route of incoming air has been marked. (Clockwise from top in figure: Inside wall / inside / Crawl space / Crawl space / inside)

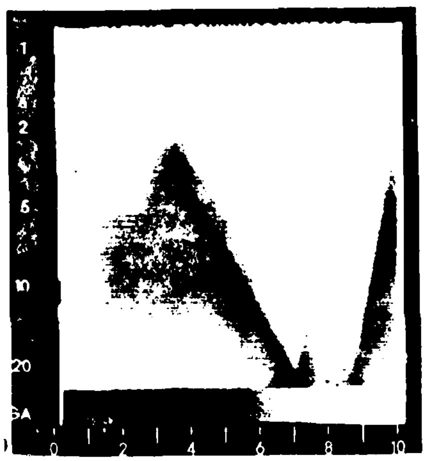
b) Thermogram of cooled surface portion where inside wall connects with joist tier. Cooling caused by inward air leakage through open joint between joist tier components.

d) $t_{ref}$ = + 22°C

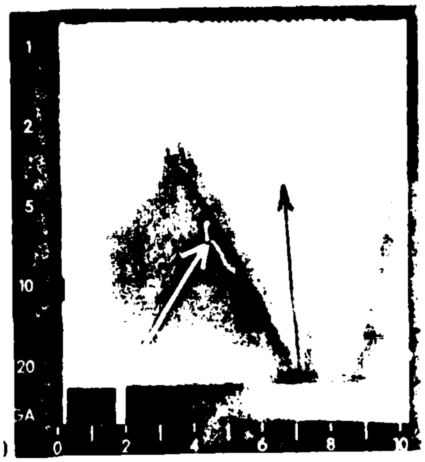
$\Delta I$ = - 5.2 isotherm units

$\Delta t$ = 7.0°C

v = 0.5 - 1.5 m/s (at floor angle)



b)

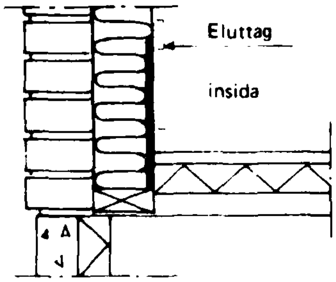


c)

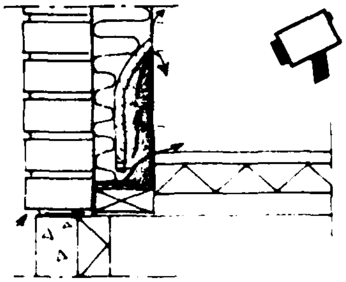
COMPARISON THERMOGRAM - OUTSIDE WALL OF WOOD WITH EXTERIOR BRICK SIDING

FIGURE 70: Deficiency in insulation and tightness due to bad filling with insulation material around electrical wiring. Polyethene (PE) foil torn.

Outside wall, from outside:
Brick facing
Sheathing
120 mm mineral wool
Polyethene (PE) foil
13 mm gypsum panel



a)


b)

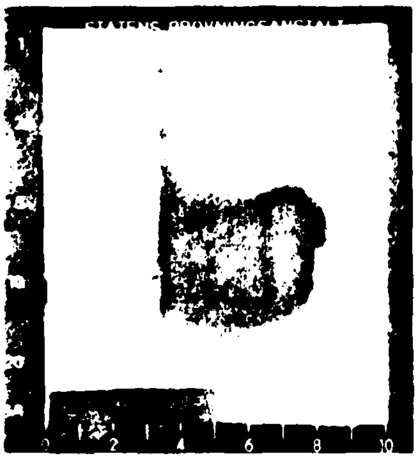
Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 20°C
Indoor air temperature: + 19°C
Wind conditions: 1 - 2 m/s (toward facade)
$p_i - p_u$: - 5 Pa

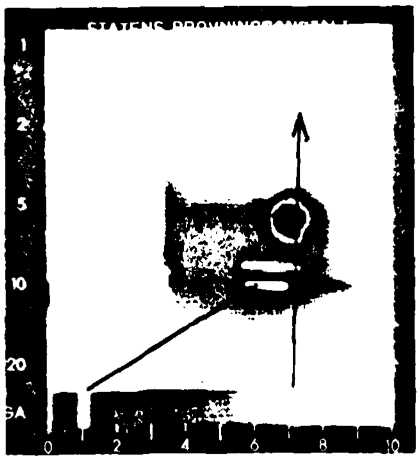
a) Construction of outside wall and joist tier in conjunction with electrical outlet (In figure: Electrical outlet ... inside)

b) Badly executed insulation around electrical wiring in the wall.

c) Thermogram of surface portion at the floor angle. The area around the electrical outlet is considerably cooled partly due to bad insulation around the electrical wiring in the wall and partly due to inward air leakage.

d) $t_{ref}$ = + 17°C
$\Delta I$ = - 6.1 isotherm units
$\Delta t$ = 10.0°C
v = 2 - 3 m/s (at electrical outlets and floor angle.

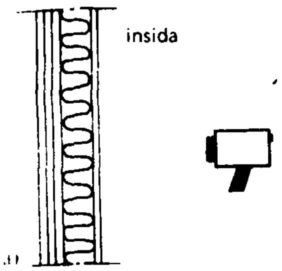

c)


d)

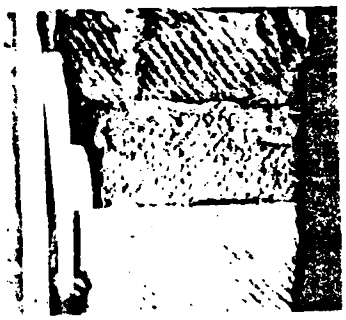
COMPARISON THERMOGRAM - OUTSIDE WALL OF WOOD WITH EXTERIOR WOOD SIDING

FIGURE 71: Deficiency in insulation and tightness due partly to insufficient filling of insulation material in the wall.

Outside wall, from outside:
Wood siding
Asphalt impregnated wood fiber board
38 x 75 mm studs
120 mm mineral wool (B qual.)
13 mm gypsum panel




a)



b)

Measuring conditions:
Cloud cover: Clear
Outdoor air temperature: - 21°C
Indoor air temperature: + 20°C
Wind conditions: 0.5 - 1.0 m/s (against facade)
$p_i - p_u$: - 10 Pa

a) Construction of outside wall (In figure: Inside)

b) Opened wall portion with bad filling of the insulation material. Insulation missing at certain points. (The wall opened from the outside).

c) Thermogram of surface portion in the middle of the wall to the left of window area. The area between the vertical studs in cooled due to lack of function of insulation.

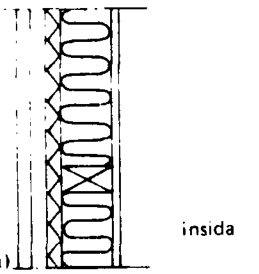
d) $t_{ref}$ = + 18°C
$\Delta I$ = - 1.2 isotherm units
$\Delta t$ = 1.5°C
$v$ = 0 m/s

d)

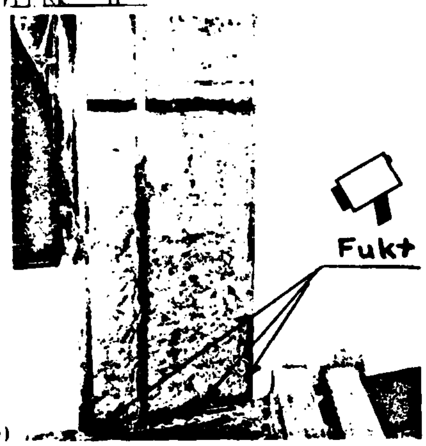
COMPARISON THERMOGRAM - OUTSIDE WALL OF WOOD WITH EXTERIOR WOOD SIDING

FIGURE 72: Deficiency in insulation due to moisture condensation in the construction. The outer insulation layer consists of styrene plastic.

Outside wall, from outside:
Wood siding
Air space
30 mm syterne cellular plastic
100 mm mineral wool (B qual.)
Polyethene (PE) foil
13 mm gypsum panel




a)




b)

Measuring conditions:
Cloud cover: Overcast (rain)
Outdoor air temperature: + 8°C
Indoor air temperature: + 19°C
Wind conditions: approx. 2 m/s (perpendicular to building facade)
$p_i - p_u$: - 4 Pa

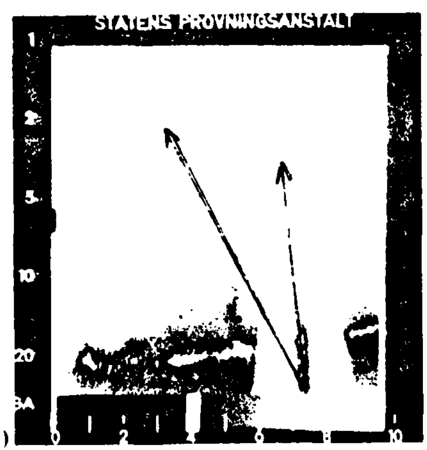
a) Construction of outside wall (In figure: inside).

b) Opened wall portion corresponding to surface portions in thermograms c) and d). Fully satisfactory insulation filling. The joist and parts of the vertical studs are moist (free water). (In figure: *Moisture*)

c) Thermogram of outside wall at floor angle. The wall surface has a slightly uneven temperature distribution. The area next to the floor is unevenly cooled due to moisture in the construction. The surface portion corresponds to the connection between the outside wall and the intermediate beam tier.

d) $t_{ref}$ = + 18°C
$\Delta I$ = - 1.8 isotherm units
$\Delta t$ = 2.5°C
v = 0 m/s


c)

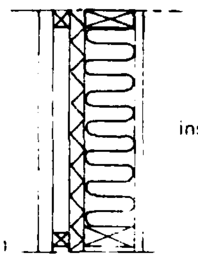


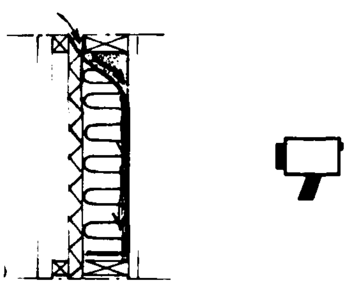

d)

COMPARISON THERMOGRAM - OUTSIDE WALL OF WOOD WITH EXTERIOR WOOD SIDING

**FIGURE 73: Deficiency in insulation and tightness due to incomplete filling of insulation material towards the warm side (air spaces).**

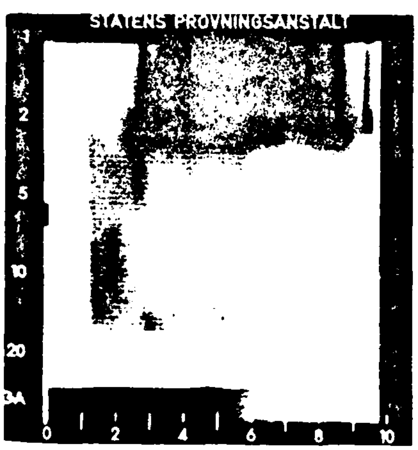
Outside wall, from outside:
Wood siding
Air space
300mmcellulose plastic
100 mm mineral wool (B qual.)
Polyethene (PE) foil
13 mm gypsum panel

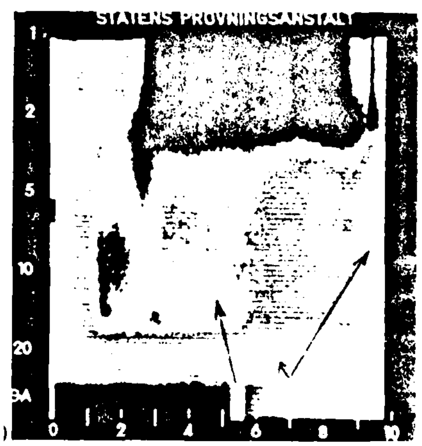



Measuring conditions:
Cloud cover: Overcast (rain)
Outdoor air temperature: + 8°C
Indoor air temperature: + 19°C
Wind conditions: approx. 3 m/s (towards facade)
$p_i - p_u$: - 5 Pa

a) Construction of ouside wall (In figure: inside)
b) Faulty execution of insulation and sealing.
c) Thermogram of wall portion below window. Uneven cooling of the wall surface is due partially to bad filling with insulation material in the wall, partially to badly executed wind barrier.
d) $t_{ref}$ = + 18°C
$\Delta I$ = - 0.9 isotherm units
$\Delta t$ = 1.5°C
v = 0 m/s

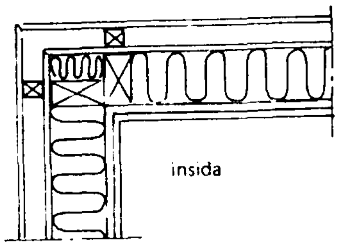


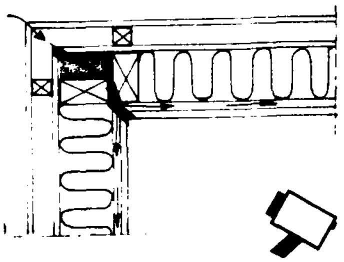
COMPARISON THERMOGRAM - OUTSIDE WALL CORNER OF WOOD

FIGURE 74: Deficiency in insulation and tightness due to absence of insulation material in a corner portion and to badly executed wind barrier.

Outside wall, from outside:
Siding plates
31 x 50 mm batten
3.2 mm - sideways internite panels
100 mm mineral wool (class A)
22 mm sheet screen
Diffusion proof cardboard
13 mm particle board




a)



b)

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: $\pm$ 0°C
Indoor air temperature: + 21°C
Wind conditions: 5 - 6 m/s (Obliquely against the facade)
$p_i - p_u$: - 2 Pa

a) Construction of outside wall (in figure: Inside)

b) Deficiency in tightness in corner

c) Thermogram of surface portion at outside wall corner. Wall and ceiling surfaces are cooled. Cooling caused by inward air leakage in channels formed in the sheet screen construction.

d) $t_{ref}$ = + 20°C
$\Delta I$ = - 1.9 isotherm units
$\Delta t$ = 2.5°C
v = 0.4 m/s (locally at the outisde wall corner.

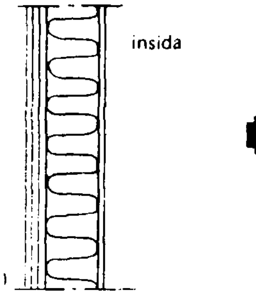

c)


d)

COMPARISON THERMOGRAM - OUTSIDE WALL OF WOOD WITH EXTERIOR WOOD SIDING

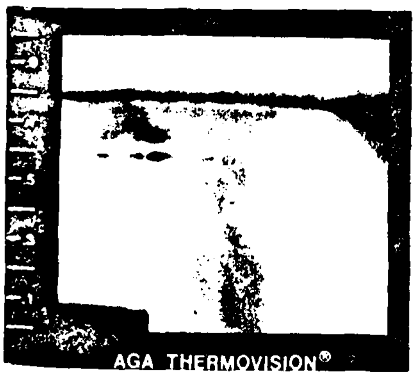
FIGURE 75: Deficiency in insulation and tightness due to incomplete filling with insulation material in the spaces between studs for the height of an entire apartment level.

Outside wall, from outside:
Wood siding
Wind barrier
95 mm mineral wool
Diffusion barrier
13 mm gypsum panel



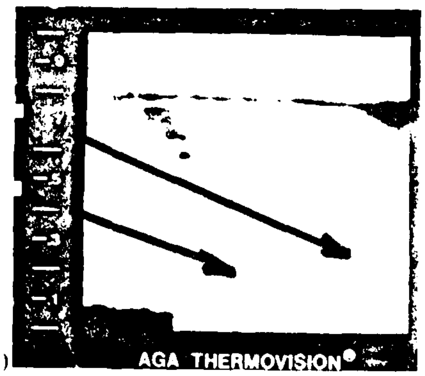

a)


b)




c)

d)




Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 1°C
Indoor air temperature: + 23°C
Wind conditions: Calm
$p_i - p_u$: - 10 Pa

a) Construction of outside wall (In figure: Inside)

b) Opened wall portion with incomplete filling of insulation material. In the spaces between the studs, the filling is uneven for the height of an entire floor level. (In figure: Beam tier / Outside wall).

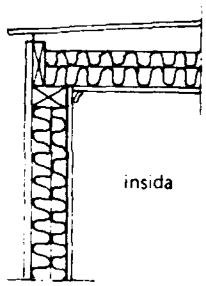
c) Thermogram of cooled wall portion. The cooled wall portion is extended vertically from floor to ceiling.

d) $t_{ref}$ = + 22°C
$\Delta I$ = - 1.4 isotherm units
$\Delta t$ = 2.0°C
v = 0 m/s

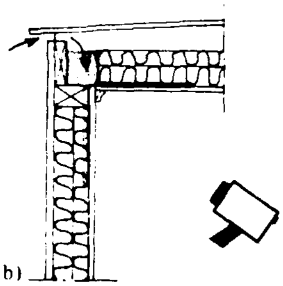
COMPARISON THERMOGRAM - OUTSIDE WALL OF WOOD WITH CONNECTION TO WOODEN TRUSS

FIGURE 76: Deficiencies in insulation and tightness due to incomplete filling of insulation material at the roof connection.

Outside wall, from outside:
Wood siding
Sheathing
70 + 50 mm mineral wool
(B qual.)
Diffusion barrier
10 mm wood fiber panel




a)



b)

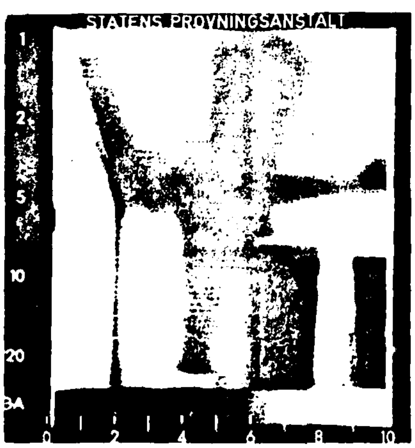
Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 5°C
Indoor air temperature: + 22°C
Wind conditions: Approx. 2 m/s (against facade)
$p_i - p_u$: - 5 Pa

a) Construction of outside wall and truss tier (in figure: inside)

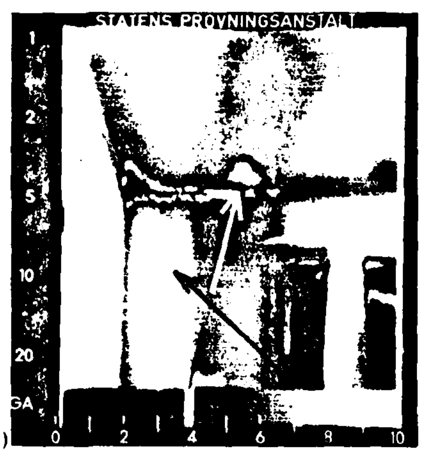
b) Deficiency in insulation and tightness.

c) Thermogram of cooled surface portion under the eaves. The uneven temperature distribution on the wall and ceiling is due to convective air movements in the construction.

d) $t_{ref}$ = + 21°C
$\Delta$ I = - 1.6 isotherm units
$\Delta$ t = 2.0°C
v = 0 m/s




c)




d)

COMPARISON THERMOGRAM - UPRIGHT MEMBER WALL OF WOOD AT CONNECTION WITH INSULATED SLOPING ROOF PORTION

FIGURE 77: Deficiency in insulation and tightness due to incomplete filling with insulation material and unsatisfactory sealing layer.

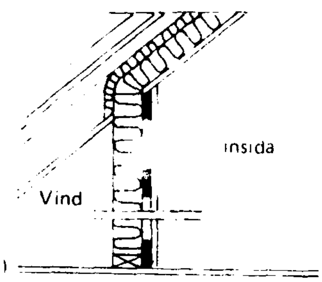
Upright member wall, from the outside:

100 mm mineral wool

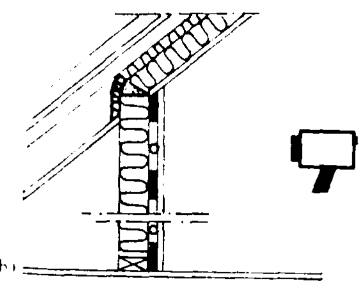
Posts, 45 x 95, approx. 600 mm

Plastic foil

Rough tongue and groove (sheet screen)




a)



b)

Measuring conditions:

Cloud cover: Overcast

Outdoor air temperature: + 2°C

Indoor air temperature: + 20°C

Wind conditions: 2 - 5 m/s (towards facade)

$p_i - p_u$: - 5 Pa

a) Construction of wall at oriel (In figure: Attic (l) / Inside (r)

b) Deficiency in insulation and tightness. Air leaks into the construction at studs and in corner areas and is propagated through channels between the panel boards.

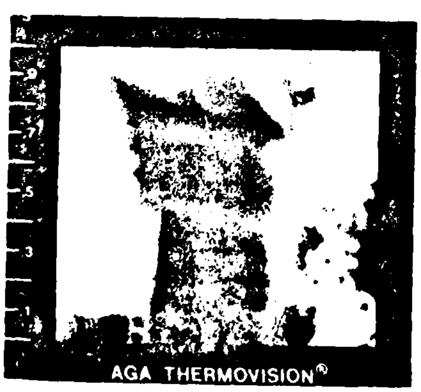
c) Thermogram of surface portion at oriel. The vertical part of the outside wall is unevenly cooled by outdoor air spreading in channels formed in the sheet screen construction.

d) $t_{ref}$ = + 19°C

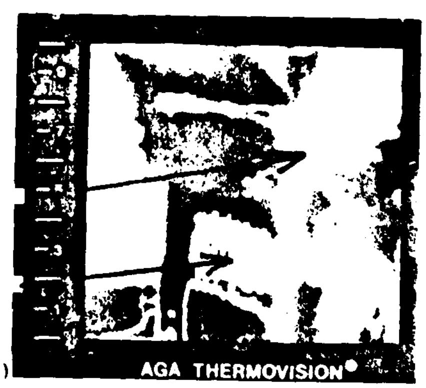
$\Delta I$ = - 1.5 isotherm units

$\Delta t$ = 2.0°C

v = 0 m/s




c)




d)

COMPARISON THERMOGRAM - OUTSIDE WALL PORTION OF WOOD AT WINDOW CONNECTION

FIGURE 78: Deficiencies in insulation and tightness due to bad fitting and contact of insulation material against the warm surface in the wall construction, in combination with convective air movements in the construction.

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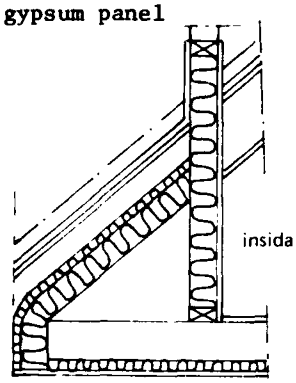
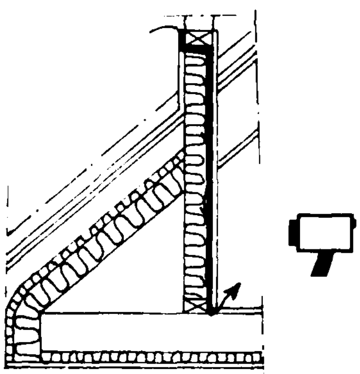
Upright member wall,
from the outside:
100 mm mineral wool (A qual.)
Studs 45 x 95, approx. 600 mm
Plastic foil
13 mm gypsum panel




a)



b)

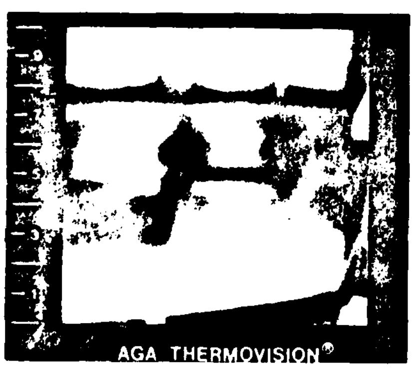
Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 2°C
Indoor air temperature: + 20°C
Wind conditions: 2 - 5 m/s (towards facade)
$p_i - p_u$: - 6 Pa

a) Construction of upright member wall at outside wall (In figure: inside)

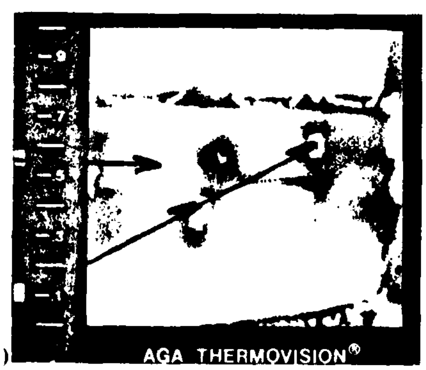
b) Unsatisfactory filling and contact of mineral wool against the warm surface (particularly at the studs).

c) Thermogram of surface portion below window. Certain areas related to studs in the wall are cooled due to malfunctioning insulation. The remarkable light surface at the lower part of the picture is caused by electrical heating panel.

d) $t_{ref}$ = + 19°C
$\Delta I$ = - 2.3 isotherm units
$\Delta t$ = 4.0°C
v = 0 m/s




c)

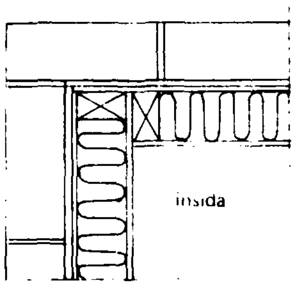


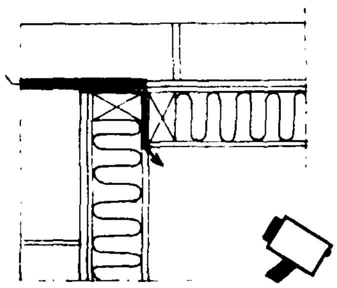

d)

COMPARISON THERMOGRAM - OUTSIDE WALL CORNER OF WOOD WITH EXTERIOR BRICK SIDING

FIGURE 79: Deficiency in insulation and tightness due to bad sealing at outside wall corners, partially also crack formation.

Outside wall, from outside
Brick facing
Air space
Wood fiber panels
100 mm mineral wool
Plastic foil
13 mm gypsum panel

a)



b)


Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: $\pm$ 0°C
Indoor air temperature: + 21°C
Wind conditions: 5 - 6 m/s (against facade)
$p_i - p_u$: - 3 Pa

a) Horizontal section of outside wall construction, corner (prefabricated wall components). (In figure: Inside)

b) Deficiency in tightness due to bad connection at wall corner.

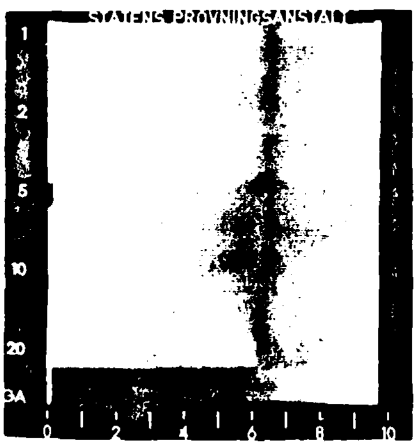
c) Thermogram of cooled surface portion at wall corner. Cooling caused by inward air leakage through vertical joint. Varying leakage through uneven air resistance of the surface layer (The wallpaper cracked in places).

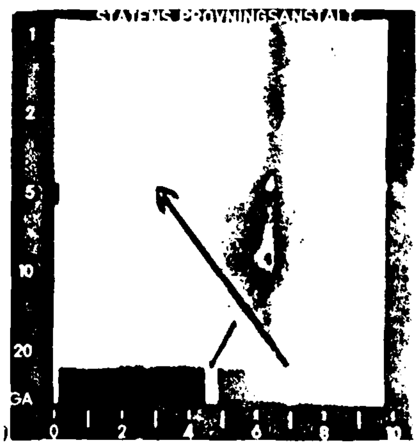
d) $t_{ref}$ = + 20°C

$\Delta$ I = - 1.3 isotherm units

$\Delta$ t = 1.5°C

v = 0.5 - 2.5 m/s (at vertical joint in the outside wall corner.

c)


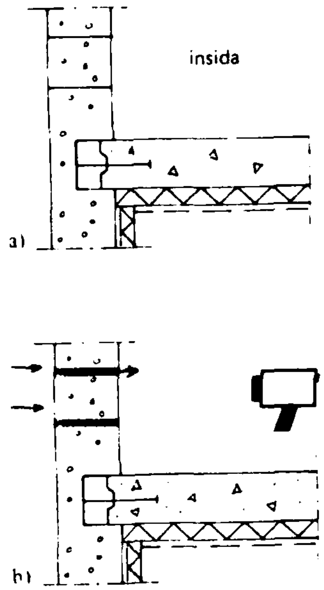

d)


COMPARISON THERMOGRAM - OUTSIDE WALL OF LIGHT CONCRETE

FIGURE 80: Deficiency in insulation and tighntness function due to crack formarions at joints both between light concrete blocks and at wall corners (connection outside wall - inside wall).

Outside wall, from outside:
Thin facing
250 mm light concrete
Thin facing

(In figure below: Inside)



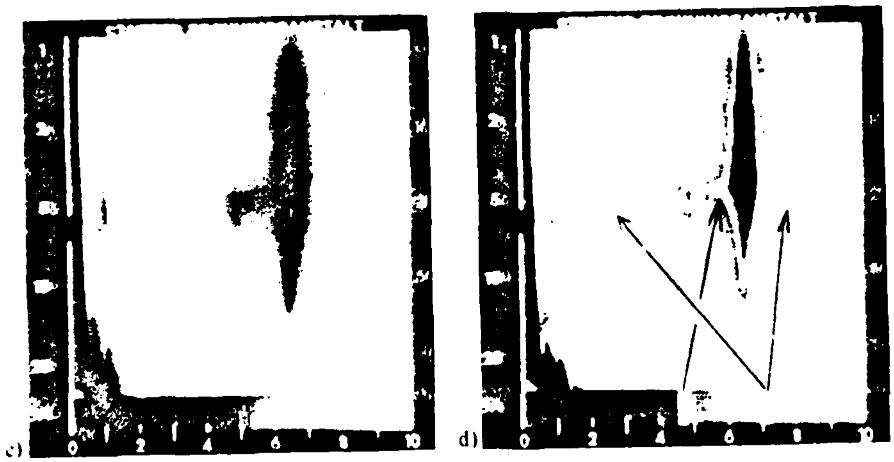

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 1°C
Indoor air temperature: + 23°C
Wind conditions: Calm
$p_i - p_u$: - 20 Pa.

a) Construction of outside wall with connection to intermediate beam tier.

b) Deficiency in insulation and tightness. Crack formation, particularly in joints between the blocks.

c) Thermogram of surface portion at wall corner to the right of window area. Block joints appear as dark lines. Certain joints and surface portions at the corner are cooled, due to air leakage inwards through (penetrating) cracks.

d) $t_{ref}$ = + 22°C
$\Delta I$ = - 1.2 isotherm units
$\Delta t$ = 1.5°C
v = 0.3 m/s (at crack in wall)
v = 0.5 m/s (at corner)



COMPARISON THERMOGRAM - OUTSIDE WALL OF LIGHT CONCRETE COMPONENTS

<u>FIGURE 81</u>: Deficiency in tightness due to penetrating crack in joint between the light concrete components.

---

Outside wall, from outside:
Facing
250 mm light concrete
Facing

In figure below: Joint between light concrete components / Inside.

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 1°C
Indoor air temperature: + 17°C
Wind conditions: Calm
$p_i - p_u$: - 3 Pa

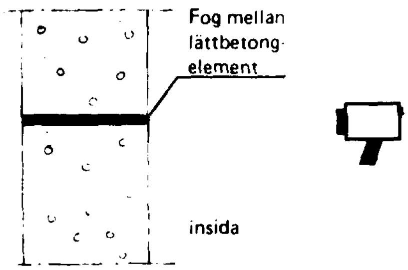
a) Construction (horizontal section) of outside wall.

b) Penetrating crack, approx. 2 mm, in joint between light concrete components.

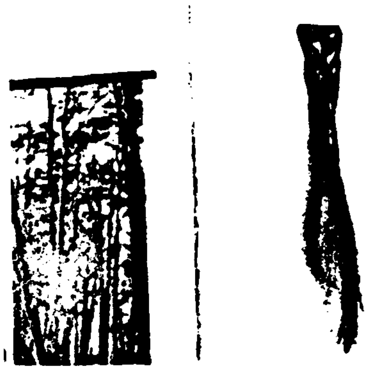
c) Thermogram of surface portion at roof angle. A cooled vertical band appears at the joint between the light concrete components. Cooling caused by inward leakage of outdoor air through the joint shown in b).

d) $t_{ref}$ = + 16°C
$\Delta I$ = - 0.8 isotherm units
$\Delta t$ = 1.5°C
$v$ = 0.3 - 0.5 m/s (at crack in joint)

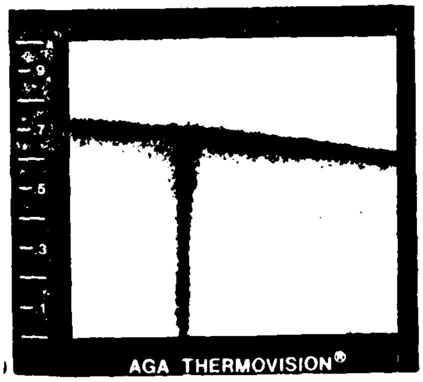
a)



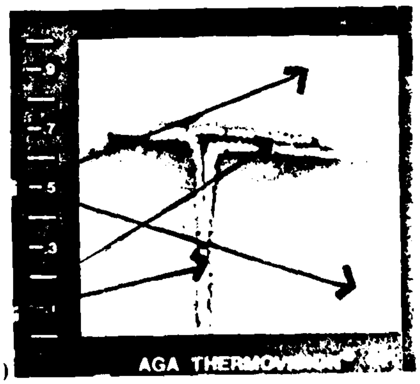

b)



c)



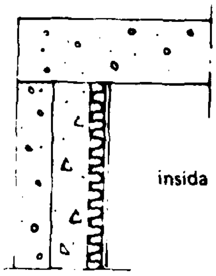

d)



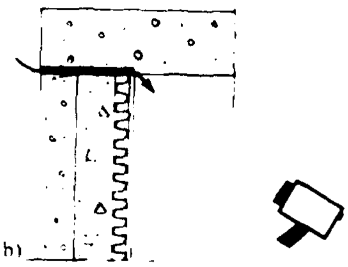
COMPARISON THERMOGRAM - CONNECTION BETWEEN OUTSIDE WALLS OF CONCRETE AND LIGHT CONCRETE

FIGURE 82: Deficiency in tightness function of outside wall, corner portion, due to crack formation in the joint between walls of concrete and light concrete.

Outside wall, from outside:
150 mm light concrete
150 mm concrete
50 mm mineral wool
13 mm gypsum panel



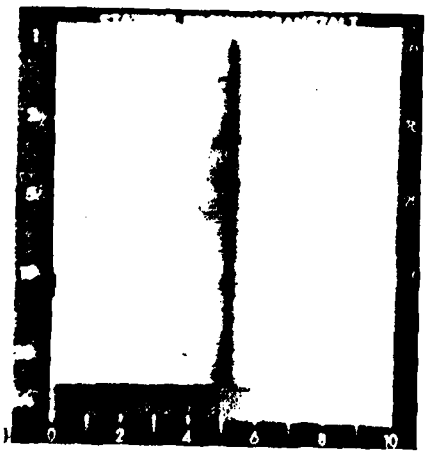

a)



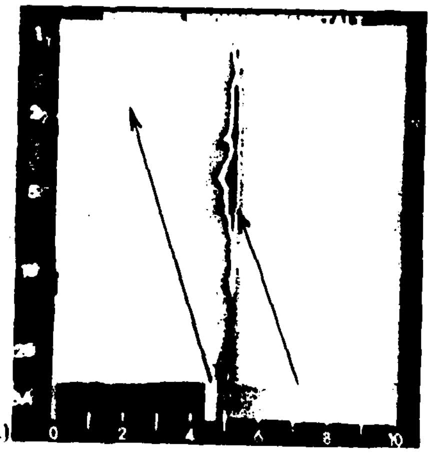
b)

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 1°C
Indoor air temperature: + 24°C
Wind conditions: Calm
$p_i - p_u$: - 20 Pa

a) Construction of outside wall where long side and gable side of building are connected. (Horizontal section).(In figure: inside).
b) Inward air leakage through joint.
c) Thermogram of surface portion at the wall corner. The cooled wall surface due to air leakage through penetrated joint in the connection between the long side and the gable side of the building.
d) $t_{ref}$ = + 23°C
$\Delta I$ = - 2.6 isotherm units
$\Delta t$ = 3.5°C
v = 1 - 3 m/s.



c)



d)

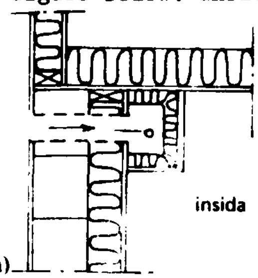
COMPARISON THERMOGRAM - OUTSIDE WALL OF CONCRETE HOLLOW BLOCKS WITH INSIDE INSULATION.

FIGURE 83: Deficiency in insulation and tightness functions of outside wall at ventilation duct due to incomplete filling with insulation material in the wall (particularly against studs).

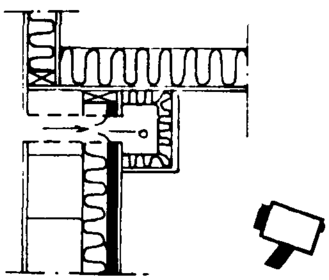
---

Outside wall, from outside:
200 mm concrete hollow blocks
70 mm mineral wool
13 mm gypsum panel

In figure below: Inside



a)


b)

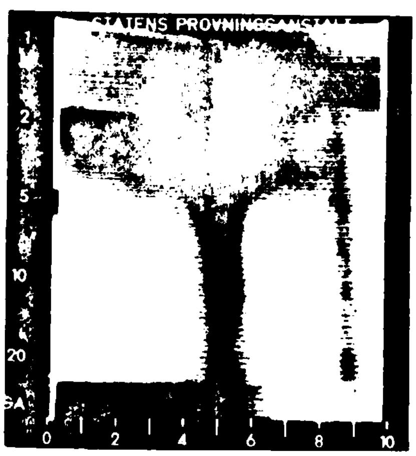
Measuring conditions:
Cloud cover: Clear
Outdoor air temperature: + 5°C
Indoor air temperature: + 21°C
Wind conditions: 2 - 3 m/s (against facade)
$p_i - p_u$: - 5 Pa.

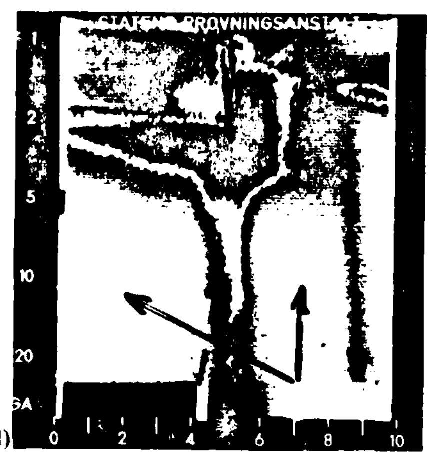
a) Construction of outside wall at ventilation duct. (Horisontal section.)

b) Unsatisfactory insulation filling in outside wall at ventilation duct.

c) Thermogram of cooled area of outside wall, at roof angle, where ventilation duct is connected. Outside air spreads in hollows formed by incomplete filling of mineal wool insulation. Cooled surface also has a vertical extension, indicating convective air flows in the construction.

d) $t_{ref}$ = + 19°C
$\Delta I$ = - 1.4 isotherm units
$\Delta t$ = 2.0°C
v = 0 m/s

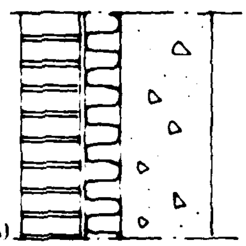
c) 

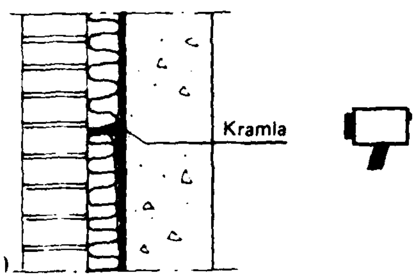
d) 

COMPARISON THERMOGRAM - OUTSIDE WALL OF CONCRETE WITH MINERAL WOOL INSULATION AND EXTERIOR BRICK FACING.

FIGURE 84: Deficient insulation function due to incomplete contact of insulation material (B quality) with the concrete.

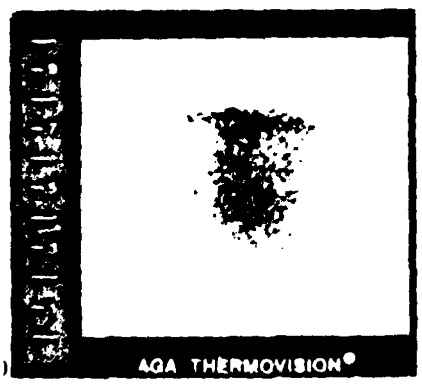
Outside wall, from outside:
120 mm brick facing (19 hole)
Air space
70 mm mineral wool, (Class B, [crumpled?])
180 mm concrete

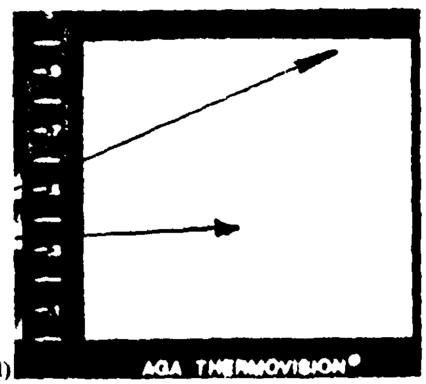
a)



b)



Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 1°C
Indoor air temperature: + 20°C
Wind conditions: Calm
$p_i - p_u$ : - 3 Pa.

a) Construction of outside wall (In figure: inside).
b) Deficiency in the insulation execution. The filling of mineral wool against the concrete is incomplete. (In figure: Crumpling[?])
c) Thermogram of surface portion in center of wall. Cooled surface appears, corresponding the corner portion of a mineral wool panel. The cooling caused by bad filling and contact against the outer side of the concrete.
d) $t_{ref}$ = + 19°C
$\Delta I$ = 0.9 isotherm units
$\Delta t$ = 1.5°C
v = 0 m/s.

c)



d)


# 6. SPECIAL DESIGNS AND CONSTRUCTION DETAILS

The investigations have shown that certain types of designs and construction details are difficult to execute in practice in such a manner that the insulation and tightness functions will be satisfactory.

This will be exemplified in the following sections. Here, investigations will be reported in the same manner as previously.

In the figures, measuring conditions and measuring values will be indicated and brief comments on the investigation in question will be given.

## 6.1. Comparative thermograms of external walls of industrial buildings

FIGURES 85-94 show some examples of deficient insulation and tightness execution in various external wall constructions designed for industrial buildings.

## 6.2. Wind barriers in external walls

Alternative designs for wind barriers, consisting of mineral wool insulation, with high density, have been tested at some projects. The results are partially shown in FIGURES 95-96.

## 6.3. Joint sealing systems

Alternative types of joint sealing systems have been tested in various investigations, and the results are shown in FIGURES 97-108. Specific attention has been given to joint sealing systems at floor angles and around windows and doors.

### 6.3.1. Joint sealing systems at floor joints

The following alternative executions of floor joint sealing have been tested with the aid of the heat camera:

a) Sealing with mineral wool strip: Gullfiber insulation 5137, FIG. 98

b) Sealing with Gullfiber joint sealing system 1610 "Fogfiber", FIG. 99.

c) Sealing with polyurethane foam of one-component type (Fogskum 100), FIG. 100.

d) Sealing with strip of EPDM rubber, Rockwool S-strip 8445, FIG. 101.

Alternatives a, b, and c have been applied and tested in three 3-level multiple dwelling houses of identical construction and located in the same area of Sollefteå.

Thermography was performed at the following occasions:

- Final inspection
- Approximately 12 months after final inspection.

Alternative d, Rockwool sealing of EPDM rubber, has been tested in two different projects, at the final inspection only. The reason for this is that the product is relatively new on the market.

Comments

Alt. a) See FIG. 98. Insulation strips of mineral wool, placed without being folded, under the floor joist, frequently cause relatively strong air leakage at the floor corner, particularly if the surface of the joist tier is uneven. Air movements measured at these leakages varied significantly, e.g. due to the pressure differences throughout the construction. When a control measurement was made twelve months after the final inspection, it was found that the extent of the air leakage had increased. The results from all houses investigated pointed in the same direction.

Alt. b) See FIG. 99. Gullfiber joint fiber system generally gave satisfactory results. Locally, a limited extent of air leakage could be observed. As a rule, there was no change in the results when measurings were made twelve months after the final inspection.

Alt. c) See FIG. 100. Generally, the results of the investigations of polyurethane foam insulated joints were good. Both the tightness and the insulation values were satisfactory. At some isolated point, a blister had formed in the material, which caused a certain air leakage. The results of measurements twelve months after the final inspection were unchanged and satisfactory.

Alt. d) See FIG. 101. Sealing with EPDM rubber insulation gave satisfactory results at the times of investigation. The results appeared to be comparable to those from alternative b). No noticeable change in the function was found in a control measurement twelve months after the first measurement.

### 6.3.2. Sealing systems around windows and doors

The following alternative executions of sealing around windows and doors have been tested with the aid of the heat camera.

a) Gullfiber caulking strip type 5097 (5 cm wide), single layer, not folded. See also FIG. 97 and 102-103.

b) Gullfiber system 1610, joint fiber. See FIG. 104.

c) Joint spraying with polyurethane foam of one-component type (Fogskum 100). See FIG. 105.

The thickness of the joint was the same for all alternatives, 15 $\pm$ 5 mm.

Systems a) - c) have been installed and tested in certain parts of three

3-level multiple dwelling buildings located in the same area of Skellefteå, as well as in two 3-level multiple dwelling building of identical construction and located in the same area of Lysekil.

Investigation of the different alternatives, with the exception of alternative c), was performed on the following occasions:

- In conjunction with the final inspection.
- Approximately two months after the final inspection.
- Approximately twelve months after the final inspection.

Comments

a) The function of joints sealed with a single, unfolded caulking strip was generally unsatisfactory. Air leakage was relatively common over fairly extended areas and, to varying degrees, in large portions of the attachment of the window frames to the wall portions. The air movements in the vicinity of the air leakages varied, e.g. due to the actual pressure difference throughout the construction. When control measurements were performed two and twelve months after the final inspection, a remarkable deterioration of the tightness function was found as compared with the values obtained at the final inspection. See FIG. 102.

b) When measuring joints sealed with the Gullfiber system "Fogfiber", the results were generally satisfactory at the time of the inspection. However, a certain degree of leakage could be found at spacing wedges and in corners, where the caulking strip was not continuous. The results remained unchanged at the control measurement occasions after two and twelve months, respectively.

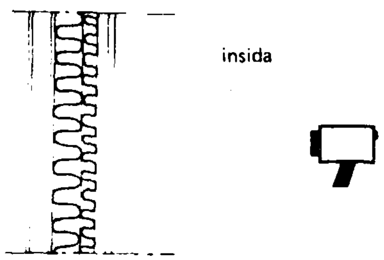
c) Sealing iwth polyurethane foam of one-component type seemed to provide good tightness, even at spacing wedges and in corners. The material in question also demonstrated good adhesive characteristics to adjacent material (with the exception of polyethene (PE) foil). There was no change in the results between the measuring occasions.

OMPARISON THERMOGRAM - INDUSTRIAL BUILDINGS - OUTSIDE WALLS WITH STEEL PROFILES (interior and exterior metal siding)

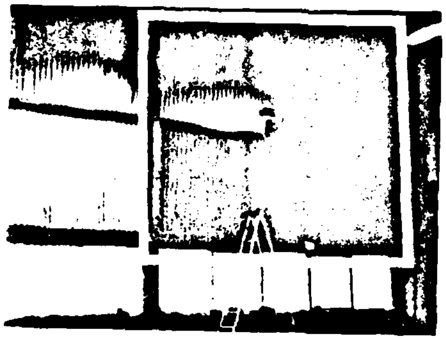
FIGURE 85: Deficiencies in insulation and tightness due to insufficient filling of insulation material in combination with bad sealing layer.

Outside wall, from the outside:
Corrugated siding
Wind barrier (paper)
70 mm mineral wool
Polyethene (PE) foil
(taped to the profile)
Corrugated metal (partially perforated)

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 3°C
Indoor air temperature: + 18°C
Wind conditions: Calm
$p_i - p_u$: - 28 Pa
(NOTE: Negative indoor pressure)




a)



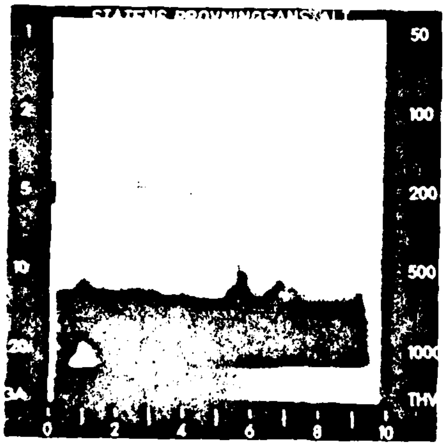
b)

a) Construction of outside wall with interior and exterior metal siding.

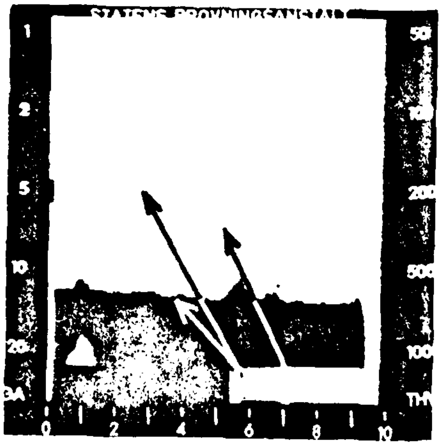
b) Inside metal surface. *Portions of the surface painted with matte, grey color (one coat).*

c) Thermogram of portion of outside wall. Certain cooled areas appear. The cooling is caused by convective air movements in the construction. Certain joints between the mineral wool panels appear as dark, vertical lines.

d) $t_{ref}$ = + 16°C
$\Delta I$ = - 0.8 isotherm units
$\Delta t$ = 1.5°C
v = 2 - 4 m/s (through joint between window and wall portion)



c)

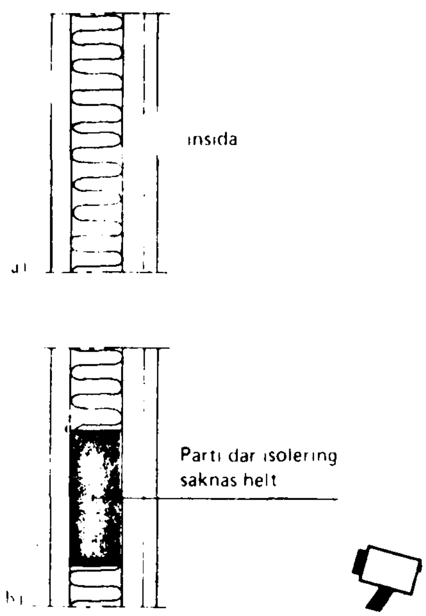


d)

COMPARISON THERMOGRAM - INDUSTRIAL BUILDINGS - OUTSIDE WALLS
WITH STEEL PROFILES (interior and exterior metal siding)

FIGURE 86: Deficiencies in insulation and tightness due to totally or partially eliminated insulation material in certain portions, locally in the structure.

Outside wall, from the outside
Trapeze-corrugated steel plate
Sheathing paper
95 mm mineral wool (A quality)
Polyethene (PE) foil
Air space
Trapeze-corrugated steel plate



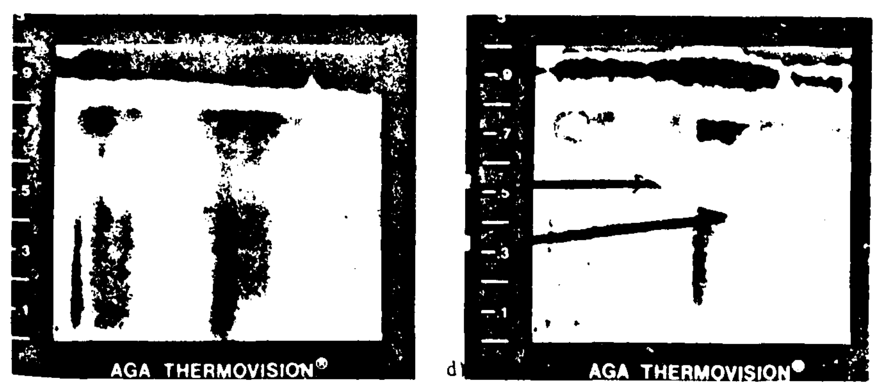

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 1°C
Indoor air temperature: + 12°C
Wind conditions: 3 - 4 m/s (against facade)
$p_i - p_u$: - 15 Pa

a) Construction of outside wall with interior and exterior metal siding. (To the right in picture: Inside)

b) Insulation missing for the entire thickness of some parts of the wall. (To the right in picture: Portion where insulation is totally absent).

c) Thermogram of cooled surface portion in the middle of wall. The defect is related to total absence of insulation material in certain portions of the wall.

d) $t_{ref}$ = + 11°C
$\Delta I$ = - 1.0 isotherm unit
$\Delta t$ = 2.0°C
v = 0 m/s



COMPARISON THERMOGRAM - INDUSTRIAL BUILDINGS - OUTSIDE WALLS WITH STEEL PROFILES (interior and exterior metal siding)

FIGURE 87: Deficiency in insulation and tightness due to leaking connection between outside wall and concrete foundation.

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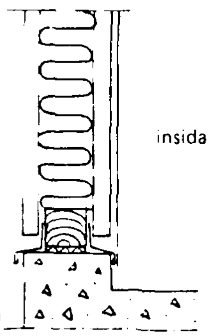
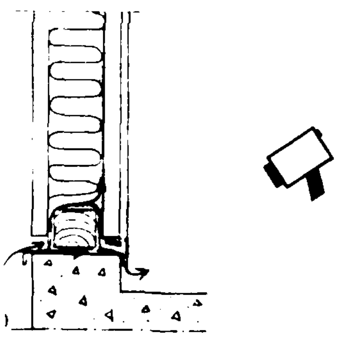
Outside wall, from outside:
Trapeze-corrugated metal plate
Sheathing paper
95 mm mineral wool
Polyethene (PE) foil
Trapeze-corrugated metal plate




a)



b)

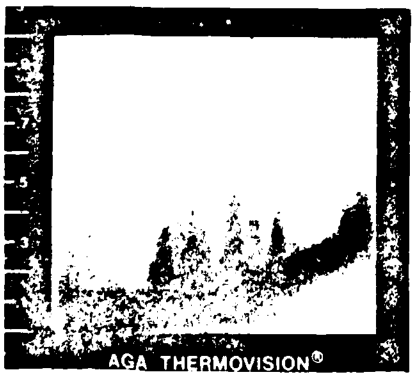
Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 1°C
Indoor air temperature: + 12°C
Wind conditions: 3 - 4 m/s (against facade)

a) Construction of outside wall with interior and exterior metal siding.

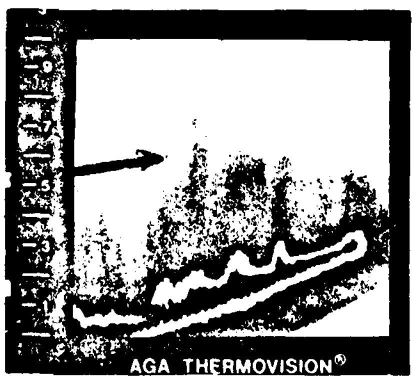
b) Bad sealing at floor andgle and insufficient filling of insulation material in wall.

c) Thermogram of surface portion at floor angle where interior metal siding meets concrete slab. Cooling caused by inward air leakage through joint between floor joist and slab. Air also propagates upward in the wall between plate and insulation material.

d) $t_{ref}$ = + 11°C
$\Delta I$ = ± 1.9 isotherm units
$\Delta t$ = 4.0°C
v = 0.5 - 2.0 m/s (at siding connection with concrete slab).




c)




d)

COMPARISON THERMOGRAM - INDUSTRIAL BUILDINGS - OUTSIDE WALLS WITH STEEL PROFILES (interior and exterior metal siding).

FIGURE 88: Deficiencies in insulation and tightness due to locally eliminated wind barrier and bad filling of insulation material in the wall.

Outside wall, from outside:
Trapeze-corrugated metal plate
Wind barrier paper board
100 mm mineral wool
Diffusion barrier

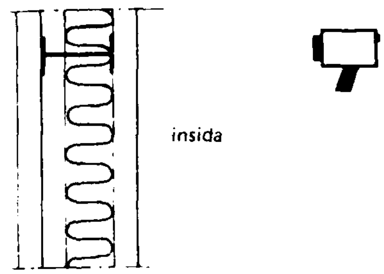
Measuring conditions:
Cloud cover: Clear
Outdoor air temperature: + 2°C
Indoor air temperature: + 17°C
Wind conditions: Approx. 3 m/s (parallel to the facade)
$P_i - P_u$: - 5 Pa

a) Construction of outside wall with interior and exterior metal siding.

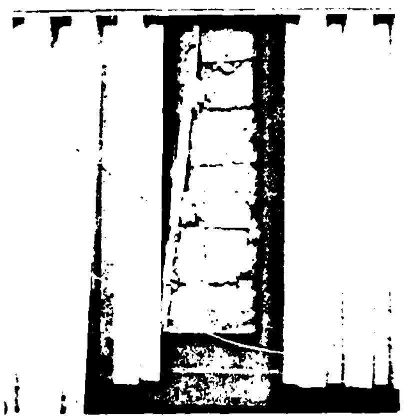
b) Opening of wall portion from the outside. Wind barrier is entirely absent in certain areas. Insulation consists of pieces of mineral wool with bad fitting.

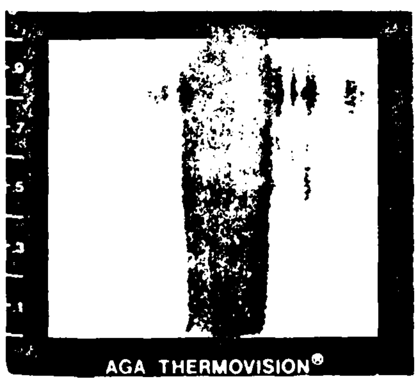
c) Thermogram of cooled wall portion. The cooling corresponds to a width of approx. 30 cm with vertical expansion of some 1.5 m.

d) $t_{ref}$ = + 16°C
$\Delta I$ = - 3.4 isotherm units
$\Delta t$ = 7.0°C
v = 0 m/s

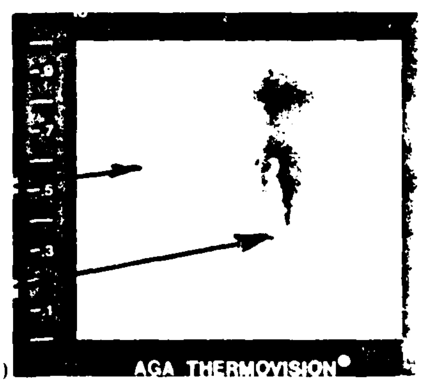


a)


b)



c)

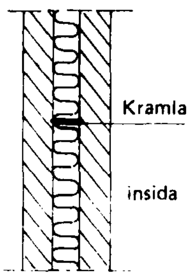


d)

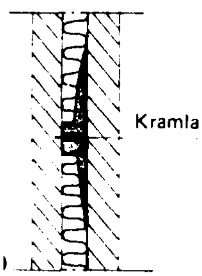
COMPARISON THERMOGRAM - INDUSTRIAL BUILDINGS - OUTSIDE WALL WITH INTERIOR AND EXTERIOR BRICK FACING.

FIGURE 89: Deficiencies in insulation and tightness due to bad filling of insulation material (B quality) in the space between the brick walls.

Outside wall, from outside:
Brick facing
100 mm mineral wool
Brick




a)




b)

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 3°C
Indoor air temperature: + 18°C
Wind conditions: 1 m/s (obliquely against facade)
$p_i - p_u$: - 7 Pa

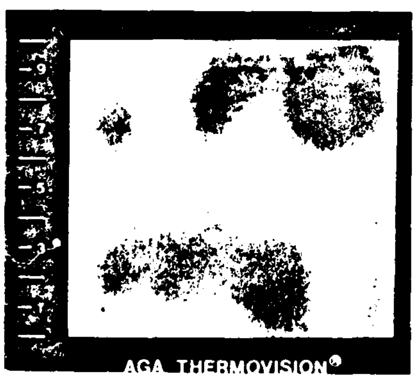
a) Construction of outside wall. (At right in picture: Clamp[?] / Inside)

b) Deficiency in insulation and tightness execution, particularly in conjunction with existing clamps[?]

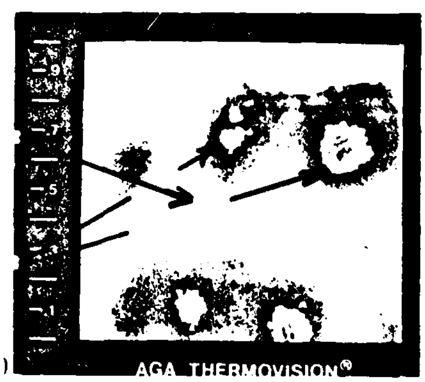
c) Thermogram of portion of outside wall. Cooled portions caused by unsatisfactory insulation execution in combination with convective air movements. The joints (corners) between the insulation panels appear as dark spots.

d) $t_{ref}$ = + 17°C
$\Delta I$ = - 0.8 isotherm units
$\Delta t$ = 1.5°C
v = 0 m/s

c)




d)



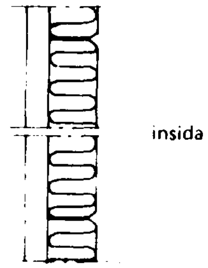
COMPARISON THERMOGRAM - INDUSTRIAL BUILDINGS - OUTSIDE WALLS
OF METAL CASEMENTS WITH MINERAL WOOL INSULATION

FIGURE 90: Deficiencies in insulation and tightness due to inward air leakage through construction of joints between the casements.

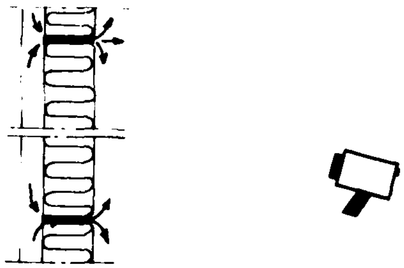
---

Outside wall, from outside:
Metal facing
100 mm mineral wool with outside heavy paper coating
Metal casements 0.6 x 6.0 m

a)




b)



Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 2°C
Indoor air temperature: + 21°C
Wind conditions: 2 m/s (from the facade)
$p_i - p_u$: - 10 Pa

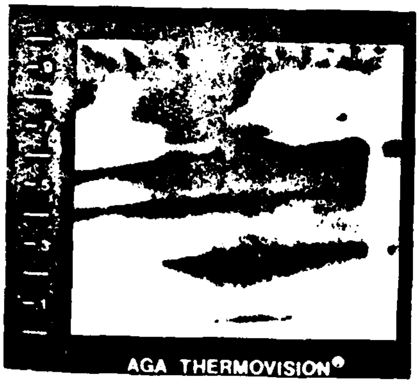
a) Construction of outside wall with interior and exterior metal siding. Metal casements with joint sealing of rubber strips. Interior metal surface was lacquered.

b) Air leakage route through the construction.

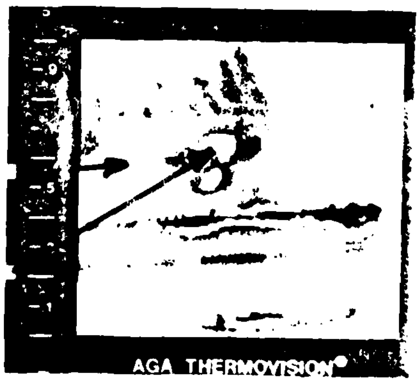
c) Thermogram of partially cooled wall portion on the upper part of the wall. The cooling is related to inward air leakage through the construction.

d) $t_{ref}$ = + 17°C
$\Delta I$ = -1.6 isotherm units
$\Delta t$ = 3.0°C
v = 1.0 - 2.0 m/s (at horizontal joint between metal casements)

c)



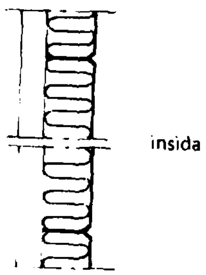

d)



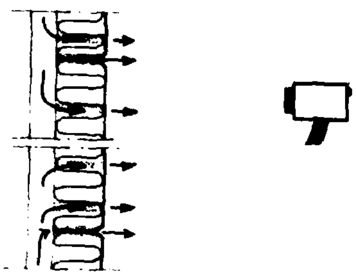
COMPARISON THERMOGRAM - INDUSTRIAL BUILDINGS - OUTSIDE WALLS OF METAL CASEMENTS WITH MINERAL WOOL INSULATION

FIGURE 91: Deficiencies in insulation and tightness due to inward air leakage through the construction at joints between the casements.

Outside wall, from outside:
Metal siding
100 mm mineral wool with outside heavy paper coating
Metal casements 0.6 x 6.0 m (perforated)



a)


b)

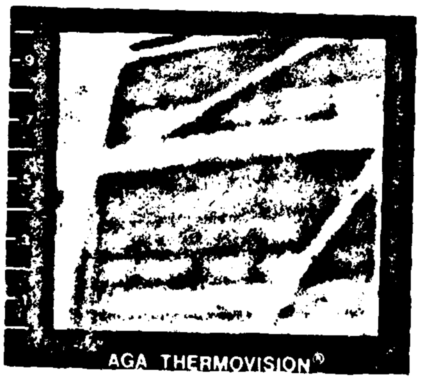
Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 2°C
Indoor air temperature: + 21°C
Wind conditions: Approx. 2 m/s (obliquely against facade)
$p_i - p_u$: - 10 Pa.

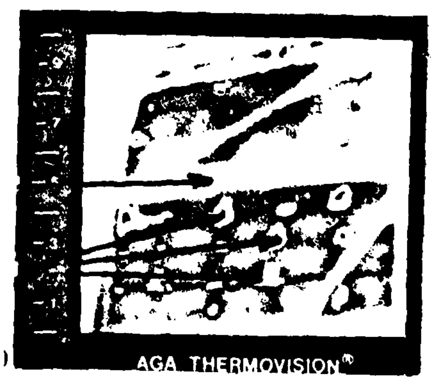
a) Construction of outside wall witn interior and exterior metal facing.

b) Air leakage through the construction at slots formed by badly fitted mineral wool panels.

c) Thermogram taken from the inside of partially cooled wall portion. The cooled portions form a certain pattern related to inward air leakage through the construction, particularly at joints between mineral wool panels, resulting in cooled surface portions.

d) $t_{ref}$ = + 20°C
$\Delta I$ = - 1.5 isotherm units
$\Delta t$ = 2.5°C
v = 0.3 - 1.0 m/s (at the wall surface. The variation over the surface is related to the performations of the metal plate.)

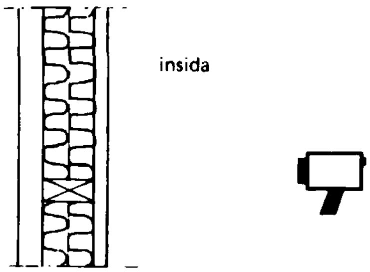
c)



d)


COMPARISON THERMOGRAM - INDUSTRIAL BUILDINGS - OUTSIDE WALLS
OF METAL CASEMENTS WITH MINERAL WOOL INSULATION

FIGURE 92: Deficiencies in insulation and tightness due to incomplete mineral wool insulation.

Outside wall, from the outside:
Corrugated metal
Sheathing paper
50 + 50 mineral wool
Polyethene (PE) foil
Corrugated metal

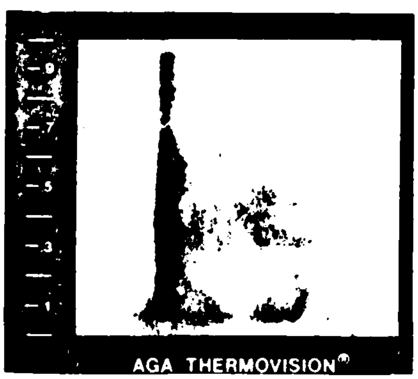



a)

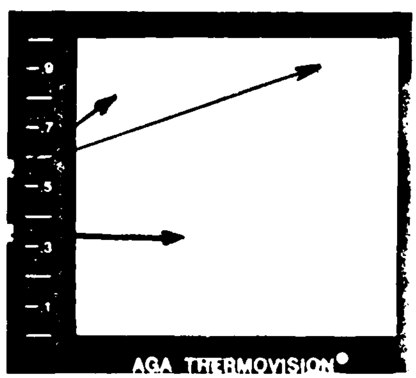
b)

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 3°C
Indoor air temperature: + 12°C
Wind conditions: 0.5 m/s (obliquely against facade)
$p_i - p_u$: - 5 Pa

a) Construction of outside wall with interior and exterior metal siding.
b) Photography of opened wall portion (from outside).
c) Thermogram of wall portion at vertical steel profile with uneven temperature distribution. The cooling of certain portions is related to deficient filling with mineral wool. Hollows in spaces between studs are due to rats having removed insulation material.
d) $t_{ref}$ = + 11°C
$\Delta I$ = - 1.1 isotherm unit
$\Delta t$ = 2.5°C
v = 0.5 - 1 m/s (at vertical post)




c)




d)

**COMPARISON THERMOGRAM - INDUSTRIAL BUILDINGS - OUTSIDE WALLS WITH STEEL PROFILES (exterior metal siding)**

**FIGURE 93: Deficiencies in insulation and tightness due to unsatisfactory contact between mineral wool insulation and steel beams.**

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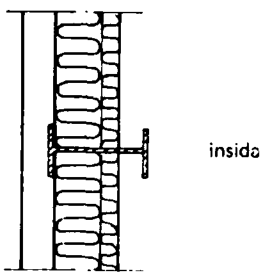
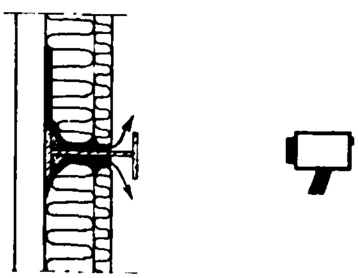
Outside wall, from outside:
Corrugated metal
90 mm mineral wool with wind barrier
Diffusion barrier
90 mm mineral wool (staple fiber)




a)

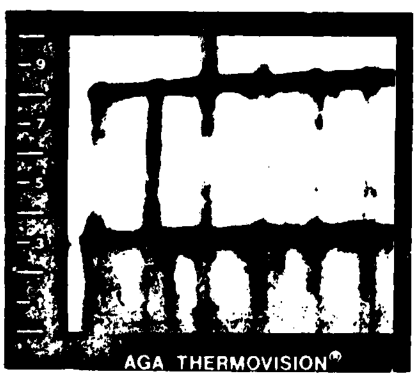


b)

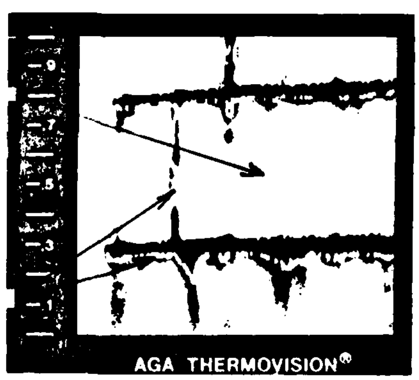
Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 1°C
Indoor air temperature: + 17°C
Wind conditions: 3 - 4 m/s (obliquely against facade)
$p_i - p_u$: - 10 Pa

a) Construction of outside wall
b) Insufficient filling of insulation material resulting in inward air leakage
c) Thermogram of cooled surface portions of outside wall. Cooling caused by inward air leakage through the construction, primarily at the horizontal steel profiles.
d) $t_{ref}$ = + 17°C
$\Delta I$ = - 1.4 isotherm units
$\Delta t$ = 2.5°C
v = 0.5 - 2.0 m/s (at the horizontal steel profiles)

c)




d)



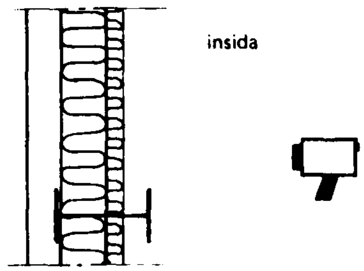
COMPARISON THERMOGRAM - INDUSTRIAL BUILDINGS - OUTSIDE WALLS WITH STEEL PROFILES (exterior metal siding)

FIGURE 94: Deficiencies in insualtion and tightness due to insufficient function of sealing layer.

---

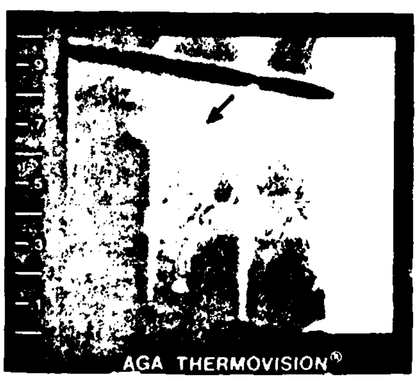
Outside wall, from outside:
Corrugated metal
90 mm mineral wool with wind barrier
Diffusion barrier
30 mm mineral wool

a)

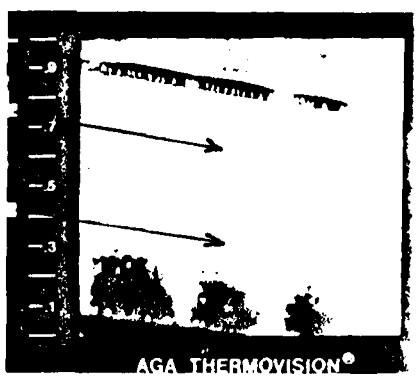



b)

c)




d)




Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 1°C
Indoor air temperature: + 18°C
Wind conditions: 3 - 4 m/s (from the facade)
$p_i - p_u$: + 10 Pa

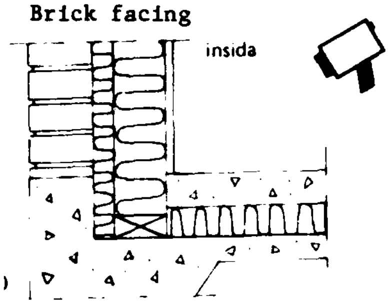
a) Construction of ouside wall
b) Outside wall seen from the inside. A darker (soiled) portion appears in the center of the wall area. The soil caused by outward leakage of dirty indoor air through local untight spots in the wall portion.
c) Thermogram of wall portion. A warm portion appears at the center of the insulated wall portion. The warming is related to outward leakage of warm air.
d) $t_{ref}$ = + 17°C
$\Delta I$ = + 0.7 isotherm units
$\Delta t$ = 1.0 °C
v = 0.2 - 0.3 m/s (outward leakage of room air)

WIND BARRIER IN OUTSIDE WALL - MINERAL WOOL INSULATION WITH HIGH DENSITY AND WITHOUT PAPER COVERING

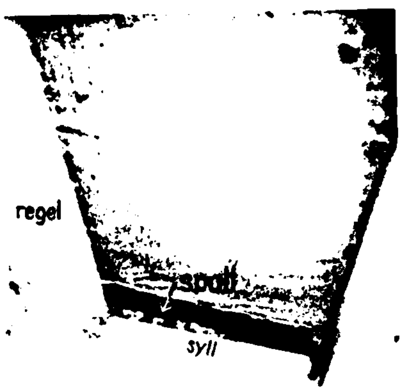
FIGURE 95: Deficient insulation and tightness function in outside wall due to outer mineral wool insulation not touching studs and joists.

---

Outside wall, from inside:
13 mm gypsum panel
Polyethene (PE) foil
95 mm mineral wool (A quality)
30 mm mineral wool (high density)
Brick facing



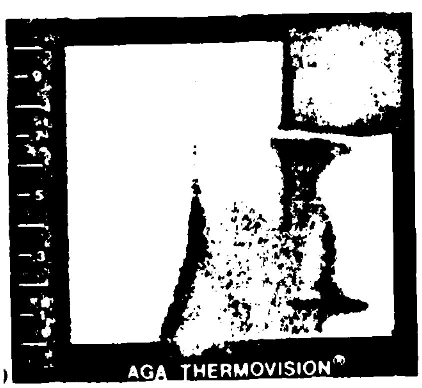

a)



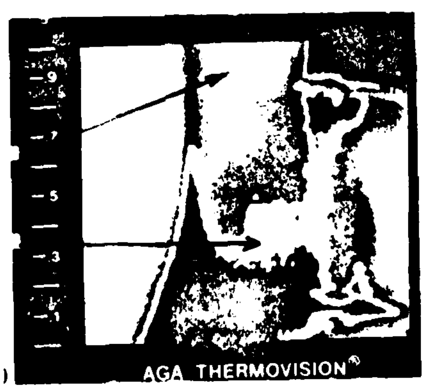

b)

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: + 4°C
Indoor air temperature: + 16°C
Wind conditions: 5 - 6 m/s (obliquely against facade)
$p_i - p_u$: - 15 Pa

a) Construction of outside wall
b) The inside of the outer mineral wool panel as placed against the studs. At the lower horizontal joist the panel is not touching the joist. There is a distance of some 3 cm.
c) Thermogram of surface portion at floor corner and wall portion to the left of and below the window. Warm radiator appears to the right in the picture (light surface). The heat distribution over the wall surface is uneven. This indicates uneven function of the wall insulation. In the wall portion there are convective air movements caused by the abovementioned deficiency.
d) $t_{ref}$ = + 15°C
$\Delta I$ = - 1.5 isotherm units
$\Delta t$ = 3.0°C
v = 1-2 m/s (at the floor board and corner)




c)



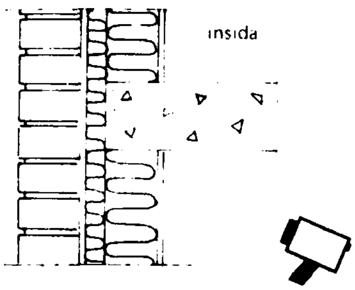

d)

WIND BARRIER IN OUTSIDE WALL - MINERAL WOOL INSULATION WITH HIGH DENSITY AND WITHOUT PAPER COVERING

FIGURE 96: Fully satisfactory insulation and tightness function of outside wall with fully satisfactory contact between outer mineral wool insulation and studs and joists.

---

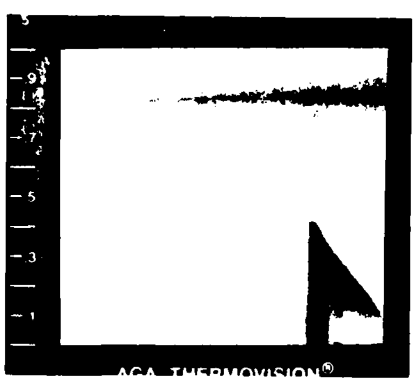
Outside wall, from inside:
13 mm gypsum panel
Polyethene (PE) foil
95 mm mineral wool (A quality)
30 mm mineral wool (Density 100 kg/m$^3$)
Brick facing

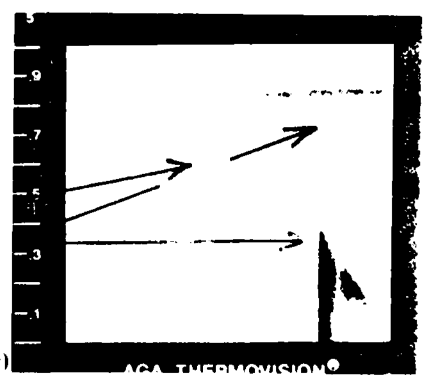



a)

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 1°C
Indoor air temperature: + 21°C
Wind conditions: 3-4 m/s (obliquely against facade)
$p_i - p_u$: - 20 Pa

a) Construction of outside wall
b) Thermogram of surface portion at ceiling angle and wall corner to the left of window. Even temperature distribution over the wall surface indicates satisfactory function of insulation and sealing of window portion.
c) $t_{ref}$ = + 20°C
$\Delta I$ = - 0.6 isotherm units
$\Delta t$ = 1.0°C
v = 0 m/s

b) 

c) 

JOINT SEALING SYSTEM - CAULKING STRIPS OF MINERAL WOOL

FIGURE 97: Correct and erroneous execution of joint sealing with mineral wool strips.

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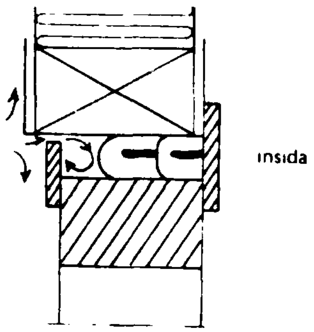


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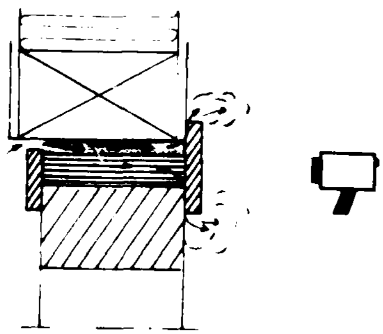


II

b)


a) Sealing of joint between door frame and wall portion should be performed accoring to I. Sealing of joint is frequently executed according to II, i.e. with only one caulking strip which is not folded. Outside air leaks inward through the untight joint. The surface portion next to the door frame on the inside of the wall will be cooled. (Top, I: Correct / Inside. II: Erroneous.)

b) Thermogram of surface portion at the joining of the door frame to the wall portion. The temperature difference between normal surface temperature and cooled area is approx. 4°C at this location. The air speed close to the inward leakage is approx. 1 m/s at the wall surface.

JOINT SEALING SYSTEM - JOIST INSULATION STRIPS OF MINERAL WOOL

FIGURE 98: Deficient function at joint at floor joist, with strong inward air leakage.

---

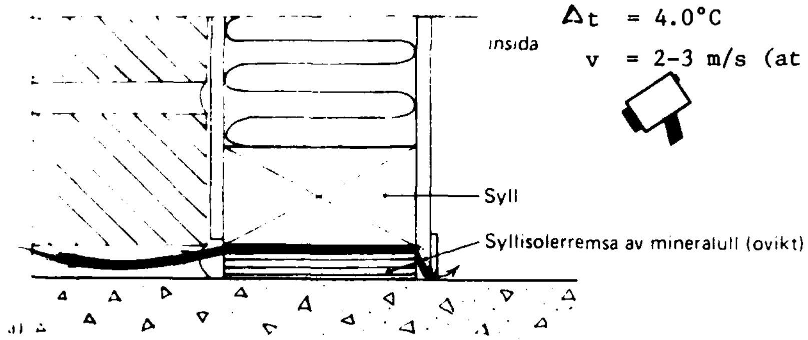
Outside wall, from outside:
Brick facing
13 mm asphalt impregnated wood fiber panel
95 mm mineral wool
Diffusion barrier
13 mm gypsum panel

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 4°C
Indoor air temperature: + 23°C
Wind conditions: 2-3 m/s (against the facade)
$p_i - p_u$: - 35 Pa

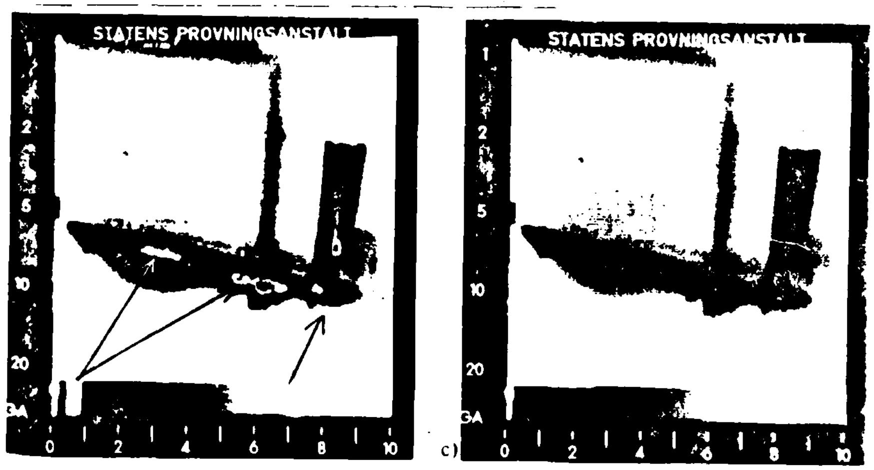
a) Joint sealing at joist with joist insulation strip of mineral wool. (Top to bottom in fig.: Inside, Joist, Joist insulation strip of mineral wool (not folded)

b) Thermogram of cooled surface portion at the floor angle. Cooling caused by inward air leakage through the joint between joist and concrete.

c) $t_{ref}$ = + 22°C
$\Delta I$ = - 3.2 isotherm units
$\Delta t$ = 4.0°C
v = 2-3 m/s (at floor edge)




a)




b) c)

JOINT SEALING SYSTEM - JOIST INSULATION WITH "FOGFIBER" SYSTEM

FIGURE 99: Acceptable function of joint at joist with locally inconsiderable inward air leakage at edges of joint sealing material.

Outside wall, from outside:
Brick facing
Asphalt impregnated wood fiber panel
95 mm mineral wool
13 mm gypsym panel

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 12°C
Indoor air temperature: + 19°C
Wind conditions: Approx. 1 m/s (parallel to facade)
$p_i - p_u$: - 6 Pa

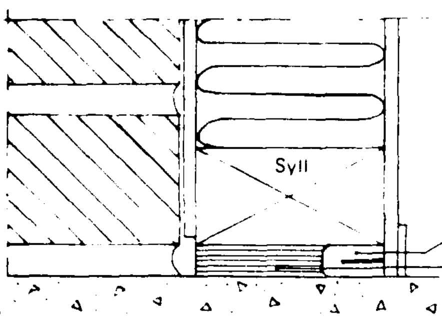
(In figure: Syll = joist; At right, top to bottom: Folded plastic surrounded insulation strip of mineral wool; Insulation strip of mineral wool, not folded.)

a) Joint sealing at joist with "Fogfiber"

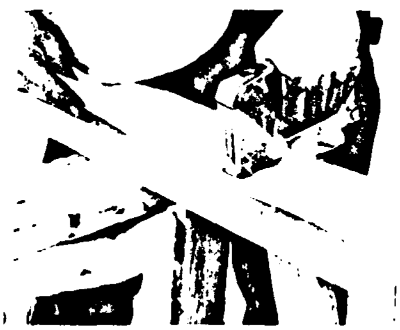
b) Photo showing application of "Fogfiber"

c) Thermogram of surface portion at floor angle. Certain limited, cooled surface portions could be observed with this system. Inward air leakage is limited and local.

d) $t_{ref}$ = + 18°C
$\Delta I$ = - 1.4 isotherm units
$\Delta t$ = 2.0°C
v = 0.2-0.3 m/s (locally)

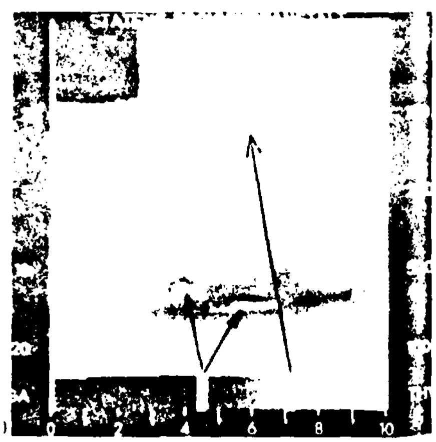



a)



b)


c)



d)

JOINT SEALING SYSTEM - JOIST INSULATION WITH POLYURETHANE FOAL

FIGURE 100: Fully satisfactory function of joint at joist.

Outside wall, from outside:

Brick facing

13 mm asphalt impregnated wood fiber panel

95 mm mineral wool

Diffusion barrier

13 mm gypsum panel

Measuring conditions:

Cloud cover: Overcast

Outdoor air temperature: - 12°C

Indoor air temperature: + 19°C

Wind conditions: Approx. 1 m/s (parallel to wall)

$p_i - p_u$: - 6 Pa

(Top to bottom in fig. a: Inside; Joist; Sealing material of polyurethane foam type)

a) Joint sealing at joist with polyurethane foam.

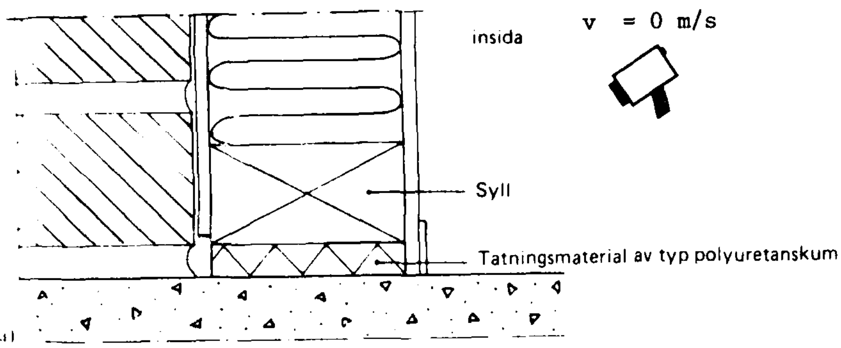
b) Thermogram of surface portion at floor angle. With the exception of a minor defect, fully satisfactory tightness was obtained with this system.

c) $t_{ref}$ = + 18°C

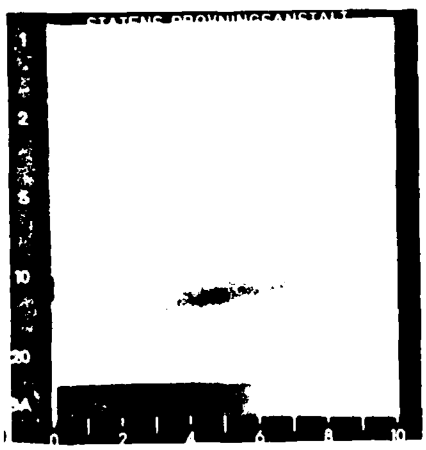
$\Delta I$ = - 1.6 isotherm units

$\Delta t$ = 2.5°C

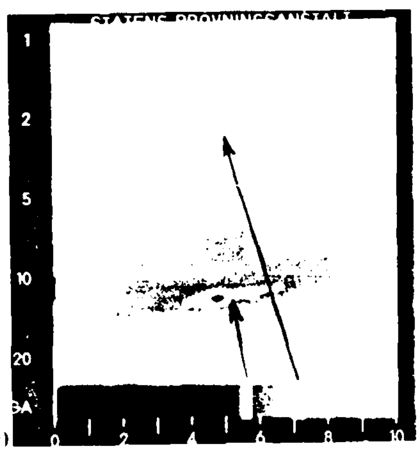
$v$ = 0 m/s




a)



b)



c)

JOINT SEALING SYSTEM - JOIST INSULATION WITH EPDM RUBBER

(Rockwool S-strip)

FIGURE 101: Satisfactory function of joint at joist

Outside wall, from outside:

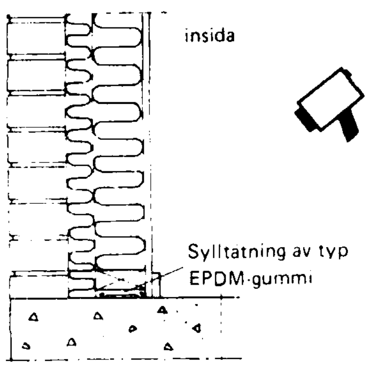
Brick facing

30 mm mineral wool

95 mm mineral wool

Diffusion barrier

13 mm gypsum panel



a)

Measuring conditions

Cloud cover: Overcast

Outdoor air temperature: + 5°C

Indoor air temperature: + 24°C

Wind conditions: 2-3 m/s (against facade)

$p_i - p_u$: - 17 Pa

(Top to bottom in figure: Inside; Joist sealing with EPDM rubber)

a) Joint sealing at joist with Rockwool S-strip

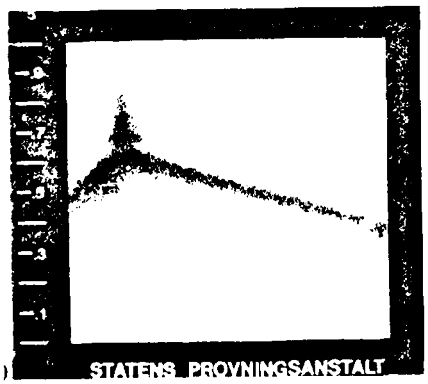
b) Thermogram of surface portion at floor angle. Satisfactory tightness obtained with this system.

c) $t_{ref}$ = + 23°C

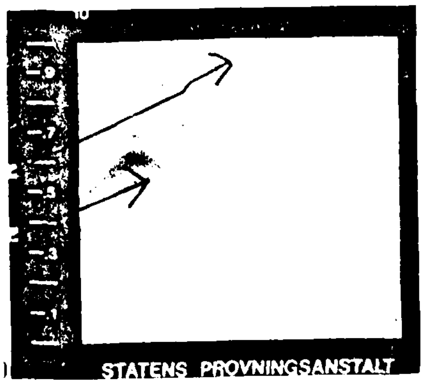
$\Delta I$ = - 2.1 isotherm units

$\Delta t$ = 3.0°C

v = 0 m/s



b)



c)

JOINT SEALING SYSTEM - WINDOW AND DOOR PORTIONS - SEALING WITH NOT FOLDED MINERAL WOOL STRIP

FIGURE 102: Deficient function of joint between window and wall (measurements at two-month interval) with deteriorated tighness two months after final inspection.

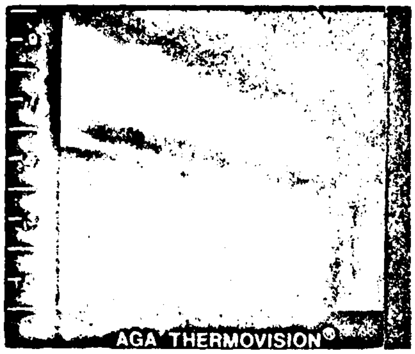
| 1st measurement: | 2nd measurement: |
|---|---|
| Measuring conditions (a and b): | Measuring conditions (c and d): |
| Cloud cover: Overcast | Cloud cover: Partly overcast |
| Outdoor air temperature: + 4°C | Outdoor air temperature: + 3°C |
| Indoor air temperature: + 20°C | Indoor air temperature: + 20°C |
| Wind conditions: 5-8 m/s (against facade) | Wind conditions: 2-3 m/s (from facade) |
| $p_i - p_u$: - 25 Pa | $p_i - p_u$: - 20 Pa |

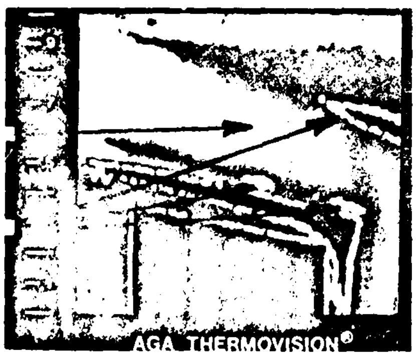
a) Thermogram of surface portion above window. Cooled area at the upper window frame. Cooling caused by inward leakage through joint between window frame and wall portion.

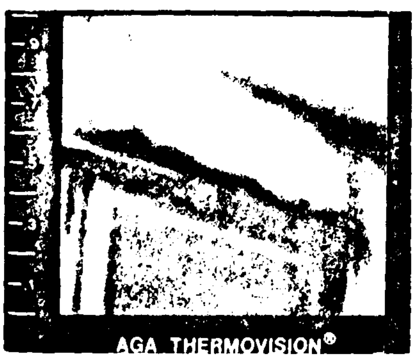
b) $T_{ref}$ = + 19°C
$\Delta I$ = - 1.6 isotherm units
$\Delta t$ = 2.5°C
v = 0.3-0.8 m/s (at joint window frame/wall)

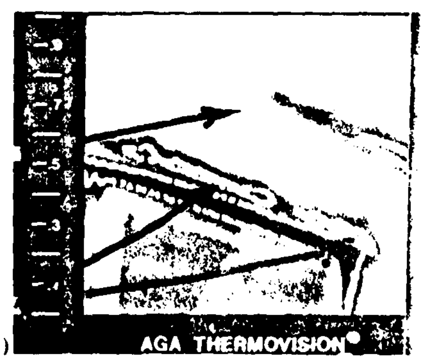
c) Thermogram of same surface portion as in a) approx. two months later. The cooled surface portions appear more clearly due to increased inward air leakage as compared to previous measurement. Air leakage through the joint has increased due to movements of the wood construction.

d) $t_{ref}$ = + 19°C
$\Delta I$ = - 2.5 isotherm units
$\Delta t$ = 4.5°C
v = 0.5-1.5 m/s (at joint window frame/wall)

a)



b)



c)



d)


JOINT SEALING SYSTEM - WINDOW AND DOOR PORTIONS - SEALING WITH NOT FOLDED MINERAL WOOL STRIP

FIGURE 103: Deficient tightness function in joint between window and wall with inward air leakage to a great extent where only one strip, not folded, was placed in the joint.

---

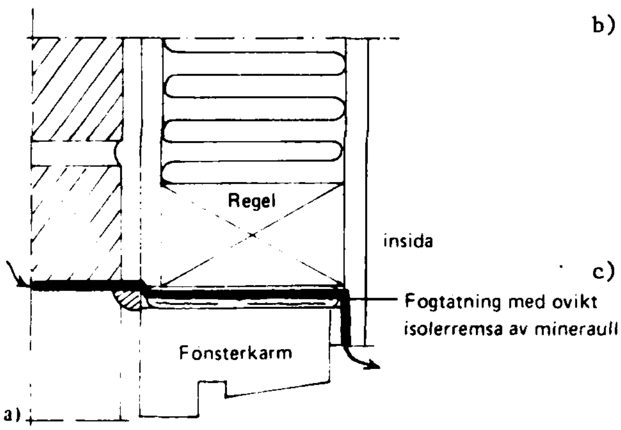
Outside wall, from outside:
Brick facing
13 mm asphalt impregnated wood fiber panel
95 mm mineral wool
Diffusion barrier
13 mm gypsum panel

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 4°C
Indoor air temperature: + 23°C
Wind conditions: 2-3 m/s (parallel with facade)
$p_i - p_u$: - 35 Pa

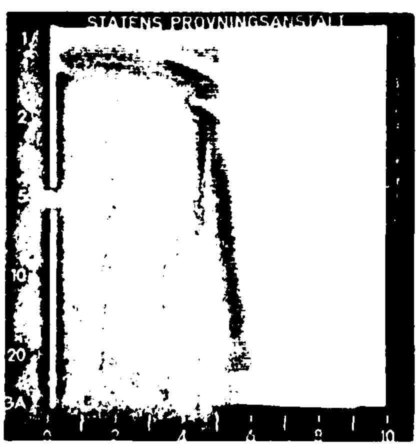
a) Sealing system between wall portion and window frame (Caulking strip of mineral wool). (In fig.: Regel = stud; insida = inside; Fönsterkarm = window frame; two lines: Joint sealing with insulation strip of mineral wool, not folded.)

b) Thermogram of surface portion at window connection to wall portion. Surface portions at joint of window frame are cooled both at upper horizontal joint and at vertical connection. Cooleing related to inward air leakage through joint between window frame and wall portion.

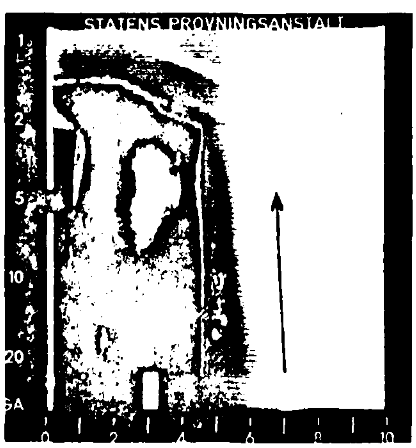
c) $t_{ref}$ = + 22°C
$\Delta I$ = - 2.0 isotherm units
$\Delta t$ = 2.5°C
v = 0.3-1.0 m/s (at connection window frame/wall)



a)



b)



c)

JOINT SEALING SYSTEM - WINDOW AND DOOR PORTIONS - SYSTEM "FOGFIBER"

FIGURE 104: Satisfactory tightness function of joint between window and wall (exception: locally at wedge).

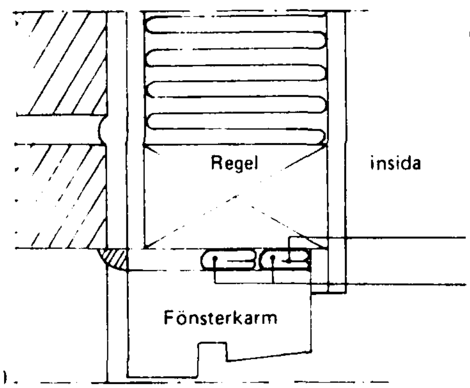
Outside wall, from outside:
Brick facing
13 mm aslphalt impregnated wood fiber panel
95 mm mineral wool
Diffusion barrier
13 mm gypsum panel

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 12°C
Indoor air temperature: + 19°C
Wind conditions: Approx. 1 m/s (parallel to facade)
$p_i - p_u$: - 35 Pa
(Clockwise from top left in fig. a: Stud; Inside; Plastic covered strip; Joint sealing with system "Fogfiber"; Window frame).

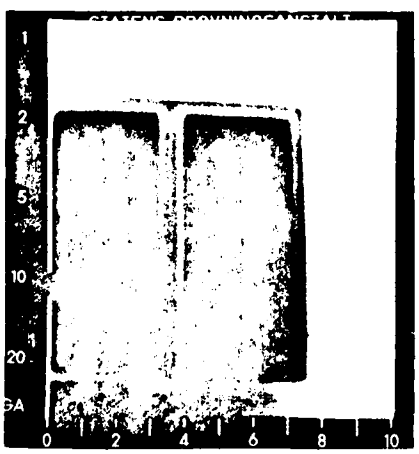
a) Joint sealing with system "Fogfiber"

b) Thermogram of surface portion at window showing fully satisfactory function of sealing of joint between window frame and wall portion.

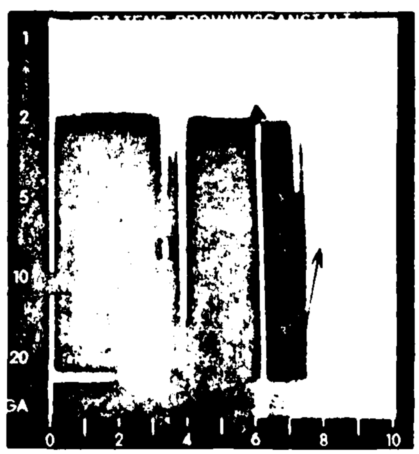
c) $t_{ref}$ = + 18°C
$\Delta I$ = - 1.0 isotherm units
$\Delta t$ = 1.5°C
v = 0 m/s




a)



b)



c)

JOINT SEALING SYSTEM - WINDOW AND DOOR PORTION - SEALING WITH POLYURETHANE FOAM

FIGURE 105: Fully satisfactory tightness fuction in joint between window and wall.

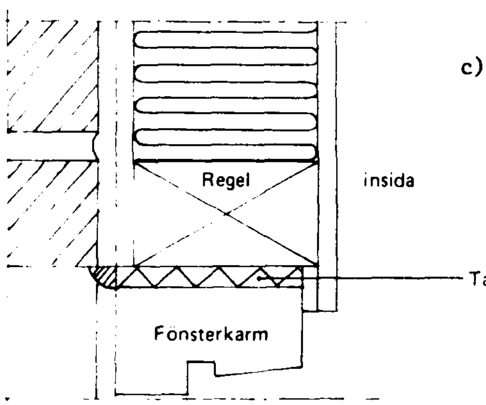
Outside wall, from outside:
Brick facing
13 mm asphalt impregnated wood fiber panel
95 mm mineral wool
Diffusion barrier
13 mm gypsum panel

Measuring conditions:
Cloud cover: Overcast
Outdoor air temperature: - 4°C
Indoor air temperature: + 23°C
Wind conditions: 2-3 m/s (parallel with facade)
$p_i - p_u$: - 35 Pa
(Clockwise, from top left in fig. a): Stud; Inside; Sealing material of polyurethane foam type; Window frame)

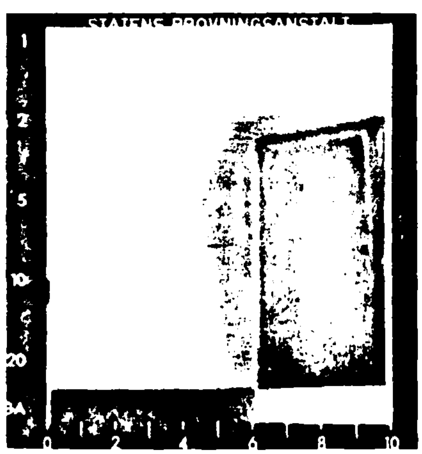
a) Joint sealing between window frame and wall with polyurethane foam.

b) Thermogram of surface portion at window connection to wall portion. Fully satisfactory function of sealing of joint between window frame and wall portion.

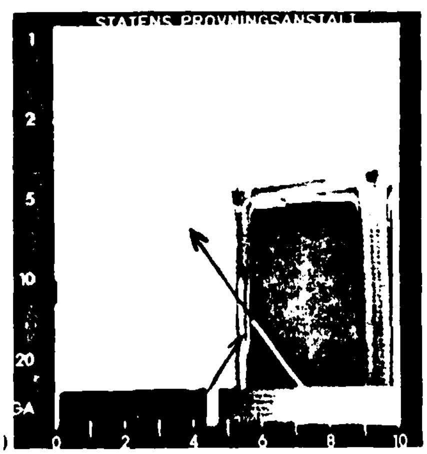
c) $t_{ref}$ = + 22°C
$\Delta I$ = - 2.7 isotherm units
$\Delta t$ = 3.5°C
v = 0 m/s




a)




b)




c)

## 7. EXAMPLES OF IMPROVEMENT METHODS

In conjunction with the investigations, thermography has also been used for the control of efficiency of certain improvement methods as well as in cases where deficiencies in the insulation and tightness execution were first observed by means of the heat camera. Such examples are shown in FIGURES 106 through 122.

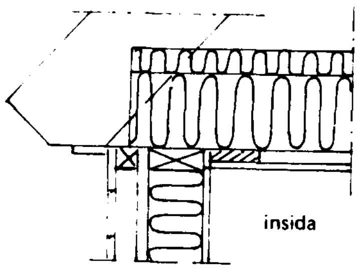
Each example is usually recorded on two pages of figures (with the exception of FIGURE 122), showing the actual construction and the deficiency observed in the insulation and tightness. Furthermore, the improvement method is indicated.

Thermogram from the surface portion under discussion are shown both before and after the improvement action. The figures contain measuring conditions and measuring values in a manner corresponding to that used for preceding chapters. Short comments on the investigation are given in conjunction with the figures.

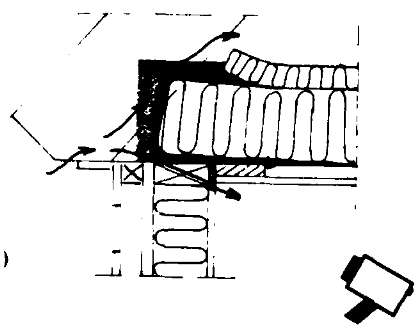
**IMPROVEMENT METHODS - ROOF TRUSS OF WOOD - ADDITIONAL INSULATION WITH CUTTER SHAVINGS AT THE SOFFIT**

FIGURE 106: Deficient insulation and tightness function at soffit. Filling with cutter shavings well packed around construction details to prevent inward air leakage into the construction. Application of particle board to obtain an air space between outside roof and mineral wool,

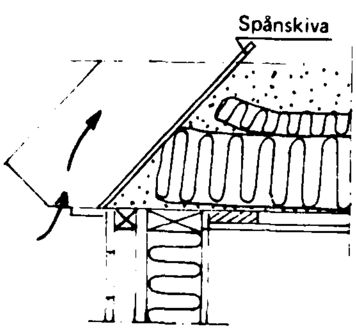
From above:
50 + 150 mm mineral wool
19 mm sheet screen
Polyethene (PE) foil
13 mm gypsum panel




a)



b)




c)

a) Construction of roof truss.

b) Observed deficiency. Unsatisfactory cutting and fitting of mineral wool on the roof truss partially due to electrical installation.

c) The following action was taken:
Filling with cutter shavings, approx. 20 cm thick, on existing mineral wool insulation, with careful packing of the material around beams at the soffit. NOTE: Particle board added at the soffit, both to place the material properly and to provide aeration for the outside roof.

Result:
The thermography study of the building after the action showed satisfactory function of both heat insulation and air tightness of the construction. Air leakage at the soffit ceased. The control was performed approx. 1 year after the first thermography, see Fig. 107.

Text in figures: a) Inside
c) Particle board

FIGURE 107: THERMOGRAMS TAKEN BEFORE AND AFTER ACTION AS PER FIG. 106

| Measuring conditions | Before action | After action |
|---|---|---|
| Cloud cover: | Overcast | Clear |
| Outdoor temperature: | - 2°C | - 17°C |
| Indoor temperature: | + 21°C | + 20°C |
| Wind conditions: | Calm | Calm |
| $p_i - p_u$: | - 5 Pa | - 5 Pa |


a)

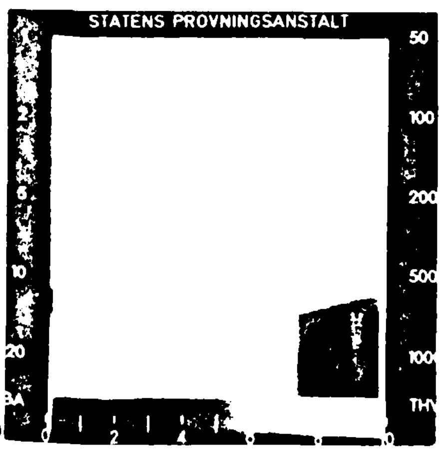

b)

a) Thermogram of cooled surface portion of roof (before action). Cooling caused by errors in insulation and tightness execution per fig. 106, b). Inward air leakage through joint at the edge of the truss.

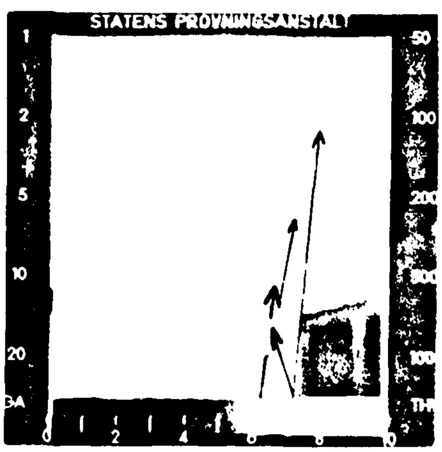
b) $t_{ref}$ = + 20°C
$\Delta I$ = - 1.9 isotherm units
$\Delta t$ = 2.5°C
v = 0.3-0.4 m/s (at roof angle)

c) Thermogram taken after action of the same surface portion of the roof as in a). The image shows satisfactory function of heat insulation and air tightness.

d) $t_{ref}$ = + 17°C
$\Delta I$ = - 0.9 isotherm units
$\Delta t$ = 1.5°C
v = 0 m/s




c)

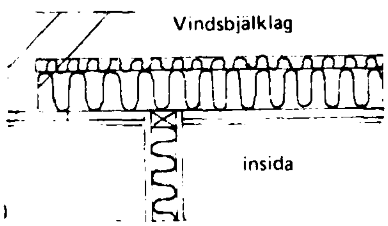



d)

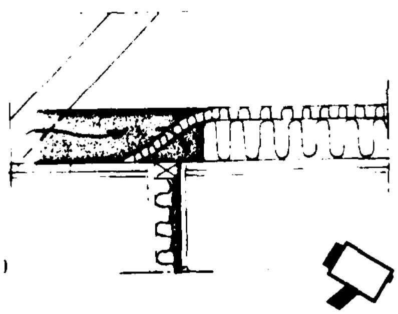
IMPROVEMENT METHODS - ROOF TRUSS OF WOOD - ADDITIONAL INSULATION WITH CUTTER SHAVINGS

FIGURE 108: Additional insulation to prevent air leakage into the construction at the soffit as well as at connections to construction wood in the beam tier.

Beam tier, from above:
50+150 mm mineral wool
19 mm sheet screen
Polyethene (PE) foil
13 mm gypsum panel




a)



b)

c)

a) Construction of beam tier at retracted balcony.

b) Deficiency observed in insulation and tightness of roof truss.

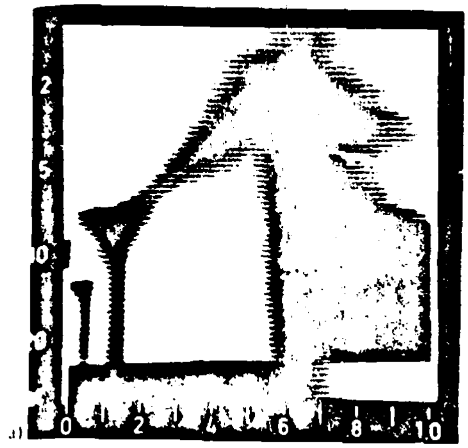
c) Insulation of the truss after additional insulation.

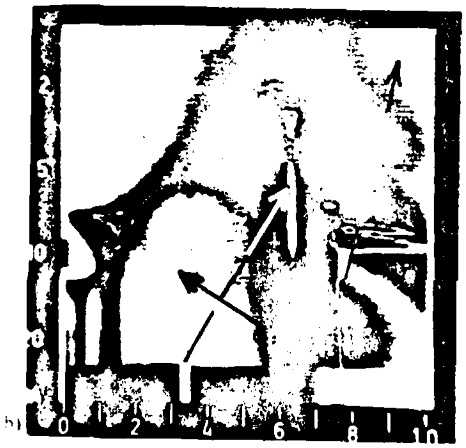
The following action was taken:
Filling with cutter shavings, approx. 20 cm on top of existing insulation of approx. 20 cm, see fig. 109.

Result:
The thermography of the building portion after the action showed significantly improved function of the construction in regard to both heat insulation and air tightness. The convective air movements in the wall portion ceased, see Fig. 109.

Text in fig. a): Beam tier for attic
Inside.

FIG. 109: THERMOGRAMS TAKEN BEFORE AND AFTER ACTION AS PER FIG. 108





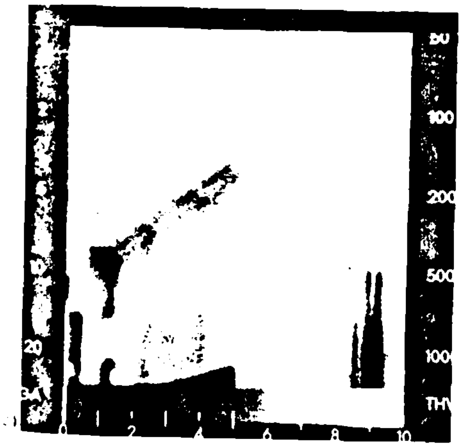
| Measuring conditions | Before action | After action |
|---|---|---|
| Cloud cover: | Overcast | Clear |
| Outdoor temperature: | - 2°C | - 17°C |
| Indoor temperature: | + 21°C | + 20°C |
| Wind conditions: | Calm | Calm |
| $p_i - p_u$: | - 5 Pa | - 5 Pa |

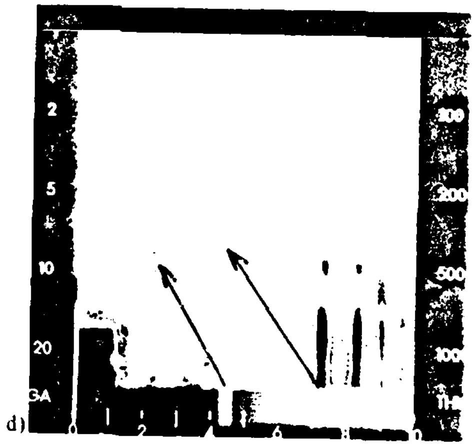
a) Thermogram of cooled surface portion at roof angle and wall to the left of glass door (before action). Cause of deficiency, see fig. 108 b.

b) $t_{ref}$ = + 20°V
$\Delta$ I = - 3.8 isotherm units
$\Delta$ t = 5.5°C
v = 0 m/s (air leakage into construction)

c) Thermogram taken after action of the same surface portion as in picture a).

d) $t_{ref}$ = + 18°C
$\Delta$ I = - 2.8 isotherm units
$\Delta$ t = 4.0°C
v = 0 m/s





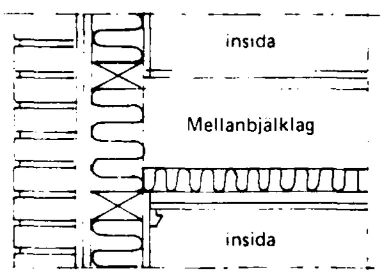
## IMPROVEMENT METHODS - BEAM TIER OF WOOD - ADDITIONAL INSULATION WITH CARBAMIDE RESIN FOAM

<u>FIGURE 110</u>: Injection of carbamide resin foam into beam tier. Satisfactory insulation and tightness function after action.

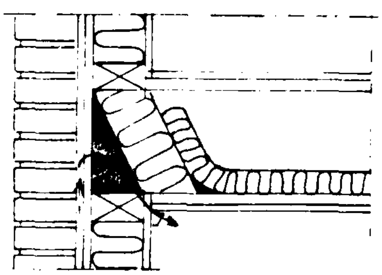
Outside wall, from outside:
Brick facing
Asphalt impregnated wood fiber panel
95 mm mineral wool
Polyethene (PE) foil
13 mm gypsum panel

Beam tier, from above:
Floor covering
Air space
50 mm minral wool (B qual.)
19 mm screen panel
13 mm gypsum panel.

Text in fig. a): Inside, beam tier, inside.



a)


b)

a) Construction of beam tier at joint with outside wall.
b) Deficiency observed in insulation and tightness.
c) The cellular plastics material after injection.

The following action was taken:
Injection of plastic foam of carbamide resin type from the outside wall and 80-100 cm into the beam tier.

Result:
The thermographic study of the building before and after action showed considerably improved function of both heat insulation and air tightness of the construction. The control was performed approx. 2 months after the action. At the opening, the shrinkage of the foam material was estimated at approx. 5%, see fig. 111.

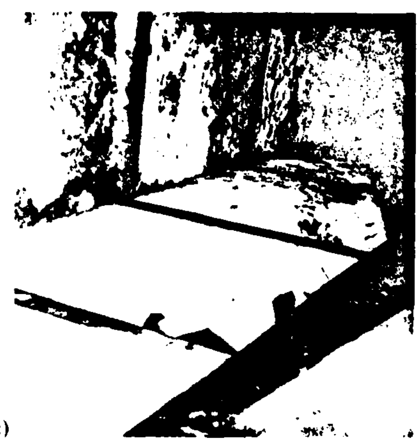
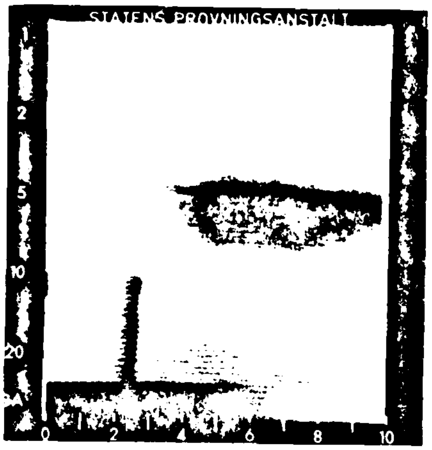

c)

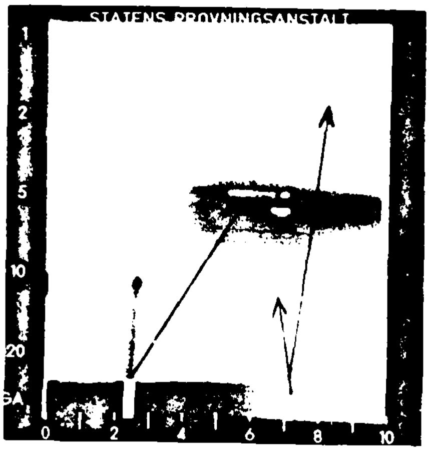
FIGURE 111: THERMOGRAMS TAKEN BEFORE AND AFTER ACTION AS PER FIG. 110.

| Measuring conditions: | Before action | After action |
|---|---|---|
| Cloud cover: | Overcrast | Clear (no sun effect on thermographed building) |
| Outdoor temperature: | - 1°C | + 4°C |
| Indoor temperature: | + 21°C | + 21°C |
| Wind conditions: | 1.0-1.5 m/s (parallel to facade) | 2 m/s (parallel to facade) |
| $p_i - p_u$: | - 5 Pa | - 5 Pa |




a)

a) Thermogram of cooled surface portion at roof angle (before action). Cooling caused by deficiency of insulation and tightness as shown in fig. 110, b).

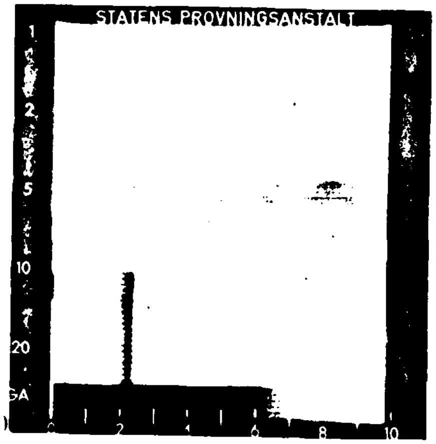



b)

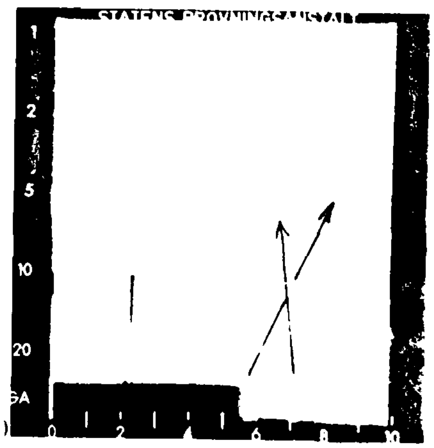
b) $t_{ref}$ = + 20°C
$\Delta I$ = - 4.8 isotherm units
$\Delta t$ = 7.0°C
v = 0.3-0.6 m/s (at ceiling angle)

c) Thermogram after action of the same surface portion shown in a). The image shows satisfactory function of insulation and tightness in the building portion.

d) $t_{ref}$ = + 20°C
$\Delta I$ = - 1.3 isotherm units
$\Delta t$ = 2.0°C
v = 0 m/s




c)



d)

IMPROVEMENT METHODS - INSULATED ROOF (SLANTING ROOF), ADDITIONAL INSULATION WITH MINERAL WOOL PANELS

FIGURE 112: Supplementation ot slantig roof insulation with mineral wool panels and adding wood fiber panel on the spar to obtain air space between insulation and wood panel. Acceptable insulation and tightness after action.

---

Slanting roof, from above:
Roof covering
Roof paneling
50 mm air space
95+50 mm mineral wool
19 mm screen panel
Polyethene (PE) foil
13 mm gypsum panel
Text in figures: a) Inside
b) Air space

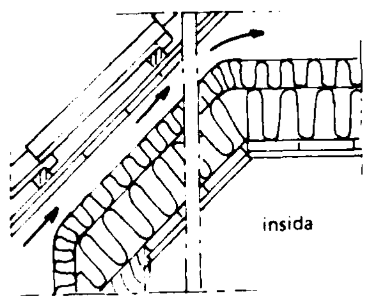
a) Construction of insulated slanting roof at finished attic (split level house).

b) Observed deficiency in insulation.

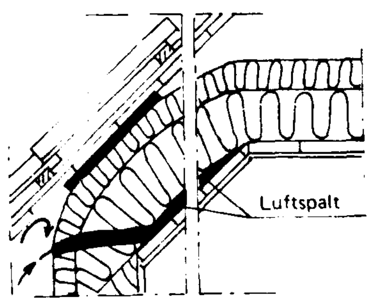
c) Sketch of action taken.

The following action was taken:
A wood fiber panel was inserted on the spar (3 spars per compartment) between the roof paneling and the mineral wool insulation so that the mineral wool insulation was packed against a warm surface, whereby a limited air space was obtained for aeration of the outside roof. The insulation material was adjusted for fitting to and contact with the truss.

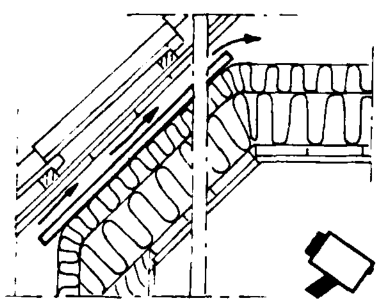
Result:
Thermography of the surface portion approx. 1 month after action showed a clearly improved function of heat insulation in the building portion, as compared with previous situation, see fig. 113.




a)




b)



c)

FIGURE 113: THERMOGRAMS TAKEN BEFORE AND AFTER ACTION PER FIG. 112

| Measuring conditions: | Before action | After action |
|---|---|---|
| Cloud cover: | Overcast | Clear (no sun effect on investigated building part) |
| Outdoor temperature: | - 1°C | + 4°C |
| Indoor temperature: | + 21°C | + 21°C |
| Wind conditions: | 1.0-1.5 m/s (parallel with facade) | Approx. 2 m/s (parallel with facade) |
| $p_i - p_u$: | - 5 Pa | - 5 Pa |

a) Thermogram of cooled surface portion at slanted roof (before action). Cooling due to deficiency described in fig. 112, b).

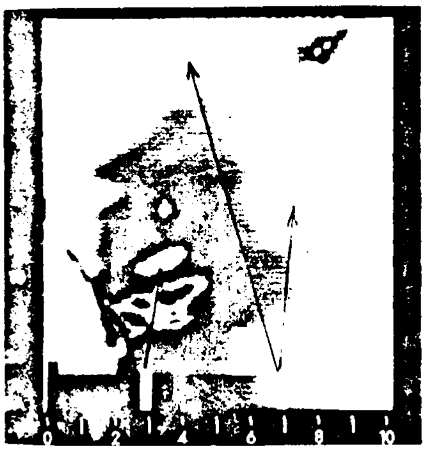
b) $t_{ref}$ = + 20°C
   $\Delta I$ = - 2.0 isotherm units
   $\Delta t$ = 3.0°C
   v = 0 m/s

c) Thermogram after action, of same surface portion as in a). The image shows significant improvement of heat insulation in the building portion. NOTE: Sun radiation through the window affects parts of the wall and roof portion (does not affect measurements on the roof).

d) $t_{ref}$ = + 20°C
   $\Delta I$ = - 1.2 isotherm units
   $\Delta t$ = 1.5°C
   v = 0 m/s

a)



b)



c)



d)


IMPROVEMENT METHODS - ROOF TRUSS OF WOOD - ADDITIONAL INSULATION WITH MINERAL WOOL AND CUTTER SHAVINGS

FIGURE 114: Supplementation of soffit insulation of saddle roof by opening the construction from the outside and insulating wth mineral wool mat with wind barrier. Tightening around the rafters wth cutter shavings. Acceptable insulation and tightness function after action.

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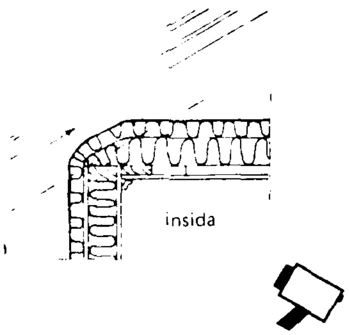
Beam tier, from above:
50 + 100 mm mineral wool
19 mm screen panel
Polyethene (PE) foil
13 mm gypsum panel

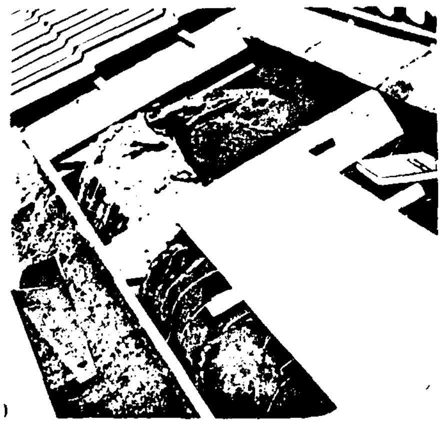



a)

a) Construction of roof truss

b) Observed deficiency of insulation and tightness (compartment at left). Improvement of wind protection and insulation shown at right in picture (performed from the outside).

c) Photo of action taken:
The following action was taken:
The mineral wool mat was lifted and cutter shavings packed around the rafters at the truss connections. The mineral wool mat was carefully replaced and fastened to the rafters. From the outside, the wind protection has been improved with a wood fiber panel.
Result:
Thermography study of the building about 5 months after the action showed satisfactory insulation and tightness functions, see fig. 115.



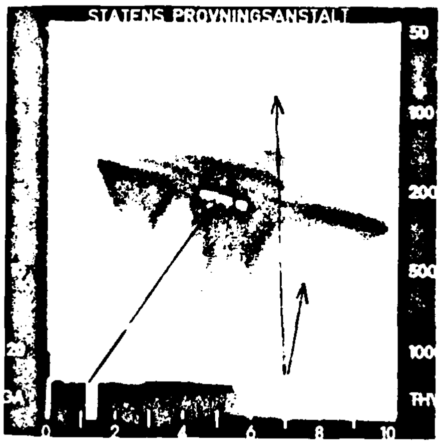
b)

c)

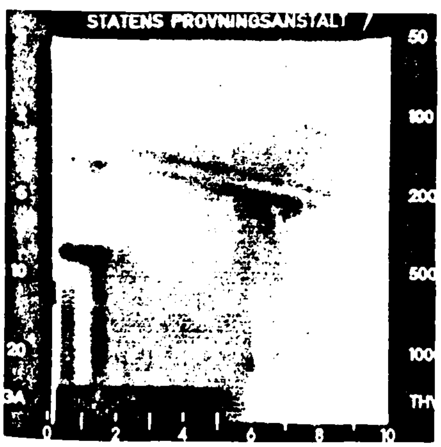
FIGURE 115: THERMOGRAMS TAKEN BEFORE AND AFTER ACTION AS PER FIG. 114

| Measuring conditions: | Before action | After action |
|---|---|---|
| Cloud cover: | Overcast | Overcast |
| Outdoor temperature: | + 7°C | + 8°C |
| Indoor temperature: | + 21°C | + 21°C |
| Wind conditions: | 2 m/s | 5-6 m/s (obliquely against facade) |
| $p_i - p_u$: | - 20 Pa | - 20 Pa |


a)




b)



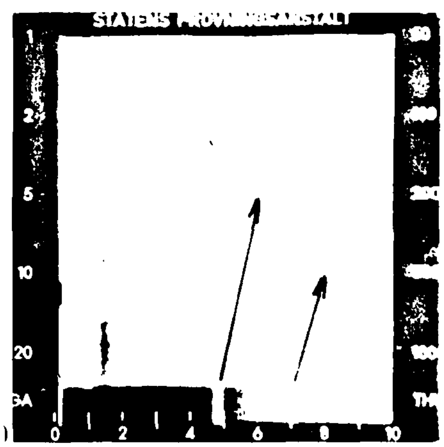

c)

a) Thermogram of cooled surface portion at roof angle (before action). Strong inward air leakage caused by deficiencies in insulation and tightness, see fig. 114 b).

b) $t_{ref}$ = + 20°C
$\Delta I$ = - 11.6 isotherm units
$\Delta t$ = 18°C
v = 1-2 m/s (approx. 60% length of joint in the foom)

c) Thermogram after action, of same surface portion as shown in a). A lesser inward air leakage can be observed at the roof angle. Insulation and tightness functions significantly improved.

d) $t_{ref}$ = + 20°C
$\Delta I$ = - 2.2 isotherm units
$\Delta t$ = 3.0°C
v = 0.5-1.0 m/s (locally and to a limited extent)




d)

IMPROVEMENT METHODS - ROOF TRUSS OF WOOD - ADDITIONAL INSULATION WITH MINERAL WOOL MAT

FIGURE 116: Supplementation of soffit insulation at saddle roof by opening from the outside. Existing mineral wool insulation has been corrected and supplemented with mineral wool mat with wind barrier which has been fastened. Acceptable insulation and tightness function after action.

---

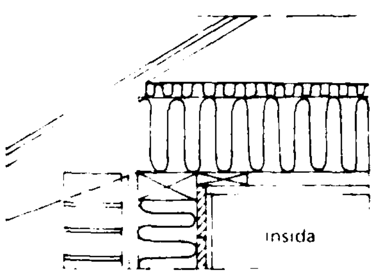
Beam tier, from above:
30 mm mineral wool mat
150 mm mineral wool felt
19 mm screen panel
13 mm wood fiber panel
Wall, from outside:
120 mm brick
Air space
13 mm asphalt impregnated wood fiber panel
120 mm mineral wool panel
Diffusion-proof paper
17 mm panel
13 mm gypsum panel

a) Construction of soffit.

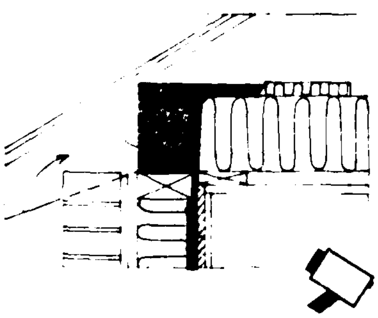
b) observed deficiency. Lack of wind protection at soffit and bad fitting of mineral wool insulation to rafters and bracings.

c) Sketch of action taken.
The following action was taken:
Correction of existing insulation against rafters and bracers. Mineral wool mat applied at soffit as protection. Mat fastened to rafters and bracings. To obtain satisfactory aeration of outside roof, a wood fiber panel was mounted on battens against the roof paneling.

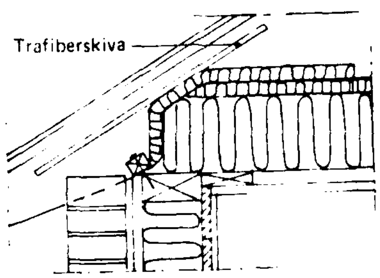
d) Photo of action taken at soffit:
Result:
Thermography study after action showed satisfactory results with good tightness at soffit and even temperature distribution over the surface. Control approx. 2 years after first thermography and approx. 6 months after action, see fig. 117.




a)



b)




c)

d)

FIGURE 117: THERMOGRAMS TAKEN BEFORE AND AFTER ACTION AS PER FIG. 116


a) b) c) d)

| Measuring conditions: | Before action | After action |
|---|---|---|
| Cloud cover: | Clear (no sun effect on part of building studied) | Overcast |
| Outdoor temperature: | + 5°C | + 1°C |
| Indoor temperature: | + 22°C | + 21°C |
| Wind conditions: | 2-3 m/s (towards building portion under study) | 1-2 m/s (obliquely towards part of building studied) |
| $P_i - P_u$: | - 3 Pa | - 5 Pa |

a) Thermogram of cooled area at roof angle (before action). Jaged form of cooled surface shows cooling caused by inward air leakage. Leakage into residential room could not be measured or observed. Cooling caused by outdoor air leaking into construction and propagating in the wall between mineral wool and gypsum panel.

b) $t_{ref}$ = + 22°C
$\Delta I$ = - 1.7 isotherm units
$\Delta t$ = 2.5°C
v = 0 m/s (no air leakage into room)

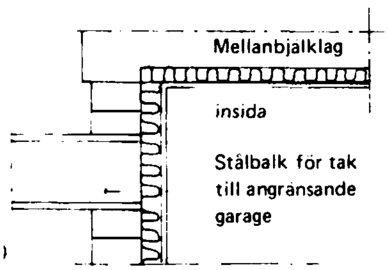
c) Thermogram of same surface portion as in a), after action. Image shows significantly better insulation and tightness functions.

d) $t_{ref}$ = + 20°V
$\Delta I$ = - 1.1 isotherm units
$\Delta t$ = 2.0°C
v = 0 m/s

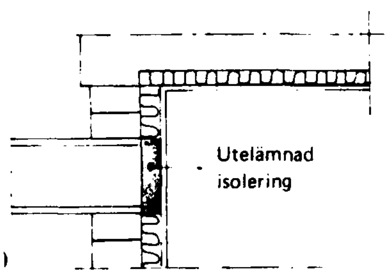
**IMPROVEMENT METHODS - OUTSIDE WALL OF HOLLOW CONCRETE BLOCKS WITH BEAM**

**FIGURE 118: Supplementation of outside wall with mineral wool panel in wall portion with cold bridge due to incomplete insulation. Fully satisfactory insulation and tightness functions after action.**

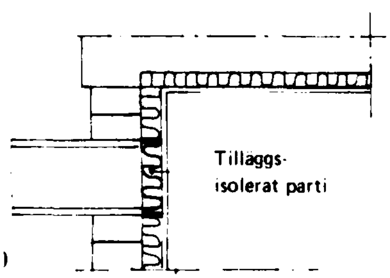
Outside wall from the outside:
Cement grout
200 mm Hollow concrete block
70 mm Mineral wood
13 mm Gypsum panel




a)




b)




c)

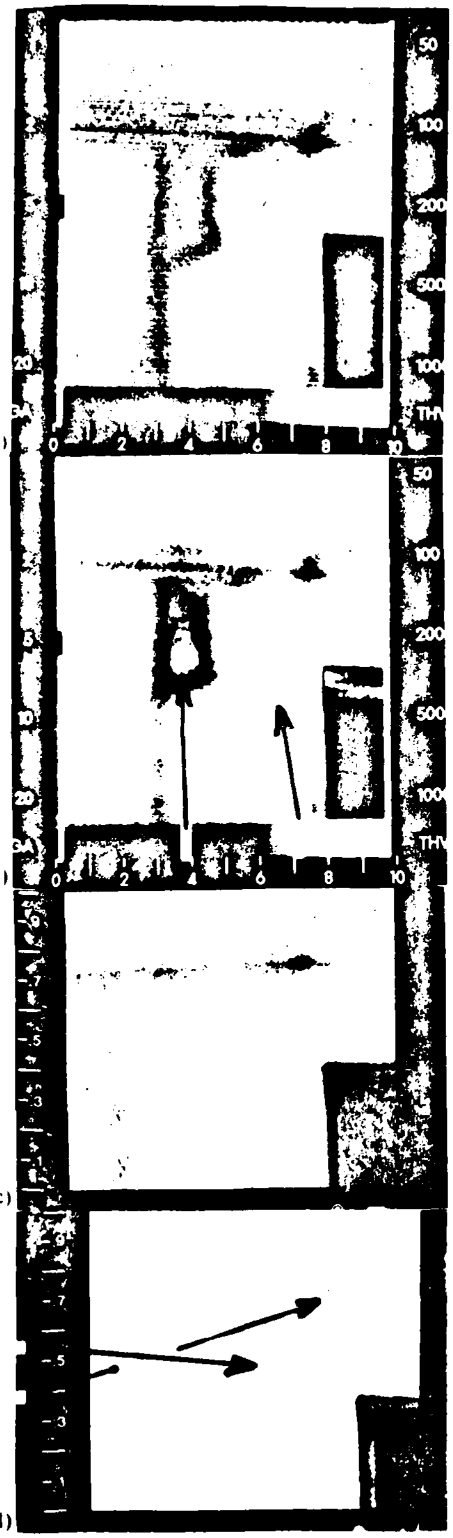
a) Construction of wall at connection to load-carrying beam.

b) Observed deficiency. Cooled wall portion due to bad insulation execution at beam connection. Insulation material lacking between steel beam and interior wall covering.

c) Sketch of action taken.

The following action was taken:
Additional insulation with 7 cm mineral wool in conjunction with opening from the inside.
Result:
Thermography of the wall portion after action shows fully satisfactory insulation function of the insulation. Control performed some 2 years after first thermography and approx. 6 months after action, see fig. 119.
Text in figures:
a) Intermediate beam tier
Inside
Steel beam for roof of adjacent garage
b) Insulation missing
c) Additionally insulated portion.

FIGURE 119: THERMOGRAM SHOWING SURFACE PORTION OF WALL BEFORE AND AFTER ACTION AS PER FIGURE 118.




| Measuring conditions: | Before action | After action |
| --- | --- | --- |
| Cloud cover: | Clear | Overcast |
| Outdoor temperature: | + 5°C | + 1°C |
| Indoor temperature: | + 21°C | + 20°C |
| Wind conditions: | 2-3 m/s (against facade) | 1-2 m/s (obliquely against facade) |
| $p_i - p_u$: | - 3 Pa | - 5 Pa |

a) Thermogram of partially cooled portion of wall surfact at roof angle (before action). Cooling caused by attachment of steel beam. Insulation on the warm side not performed, see fig. 118 b).

b) $t_{ref}$ = + 20°C
$\Delta I$ = - 1.6 isotherm units
$\Delta t$ = 2.0°C
v = 0 m/s

c) Thermogram after insulation of end portion of beam, same surface portion as picture a). Image shows fully satisfactory function of wall insulation.

d) $t_{ref}$ = + 19°C
$\Delta I$ = - 0.9 isotherm units
$\Delta t$ = 1.5°C
v = 0 m/s

IMPROVEMENT METHODS - ROOF TRUSS OF WOOD

FIGURE 120: Supplementation of beam tier insulation with mineral wool insulation. The paper backed mineral wool mat has been corrected and attached in the right position by nailing it to battens. Acceptable insulation and tightness function after action.

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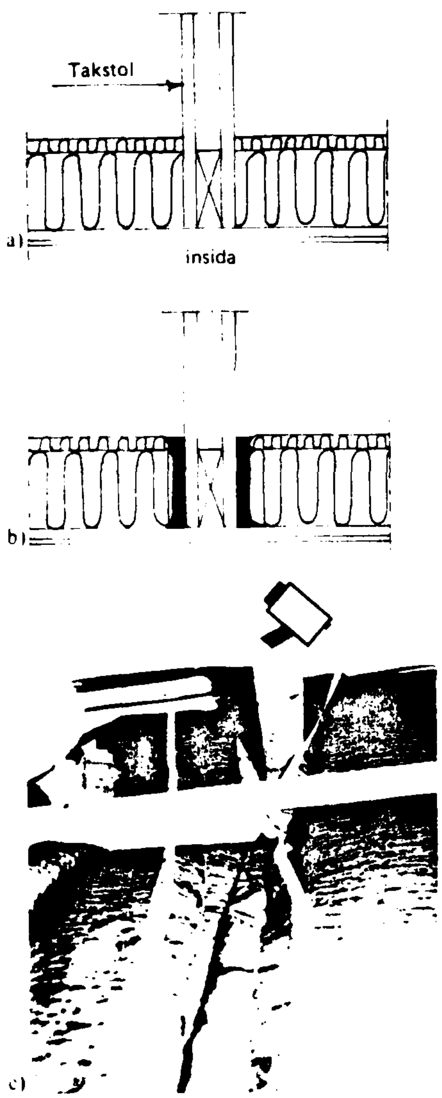
Beam tier, from above:
30[?] mm mineral wool mat
150 mm mineral wool felt
Polyethene (PE) foil
13 mm wood fiber panel




a) Construction of roof truss.

b) Deficiencies in insulation and tightness execution of beam tier at truss.

c) Insulation on beam tier after action.
The following action was taken:
The lower mineral wool panel was supplemented for fitting against the truss. The paper-coated mineral wool mat was corrected in respect to positioning on the beam tier and the mat was attached by means of battens to the soffit.
Result:
Thermography study of the building portion after the action gave satisfactory results, but a minor defect at the electrical outlet for a ceiling lamp is still visible, see fig. 121.
Text in fig. a) Roof truss
Inside.

FIGURE 121: THERMOGRAM SHOWING SURFACE PORTION OF ROOF TRUSS BEFORE AND AFTER ACTION ACCORDING TO FIGURE 120.


| Measuring conditions: | Before action | After action |
|---|---|---|
| Cloud cover: | Clear (no sun effect on part of building being studied) | Overcast |
| Outdoor temperature: | + 2°C | + 1°C |
| Indoor temperature: | + 22°C | + 21°C |
| Wind conditions: | 2-3 m/s (parallel with facade) | 1-2 m/s (obliquely against facade) |
| $P_i - P_u$: | - 3 Pa | - 3 Pa. |

a) Thermogram of cooled surface portion of ceiling and ceiling angle (before action). The shape of the cooled portion indicates convective air flows in the construction.

b) $t_{ref}$ = + 21°C
$\Delta I$ = - 1.6 isotherm units
$\Delta t$ = 2.0°C
v = 0 m/s

c) Thermogram of the same surface portion as in a), after action. Certain limited cooled areas are still visible in the ceiling surface and at the ceiling angle. However, the image shows a clear improvement in comparison with previous situation. The function of heat insulation in the building portion is acceptable.

d) $t_{ref}$ = + 20°C
$\Delta I$ = - 1.0 isotherm unit
$\Delta t$ = 1.5°C
v = 0 m/s

MPROVEMENT METHODS - OUTSIDE WALL WITH EXTERIOR METAL SIDING AND INSULATION WITH MINERAL WOOL.

FIGURE 122: Supplementation of a certain part of wall portion by means of injecting plastic foam of carbamide resin type. Portion with supplementary insulation shows satisfactory insulation and tightness functions, while no change is noted in portion where action has not been taken.

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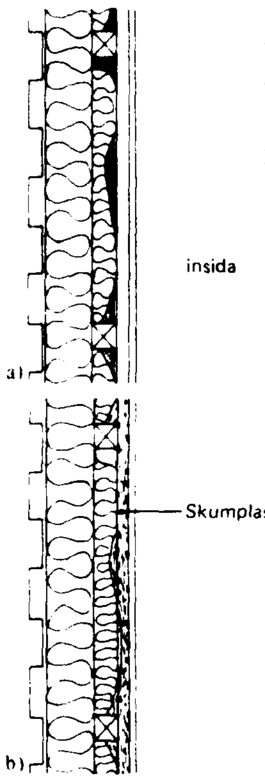
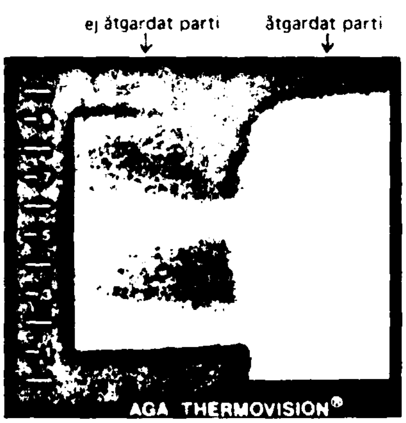


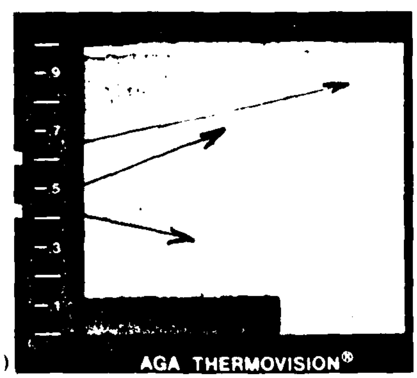

Outside wall, from outside:
Corrugated metal
100 mm mineral wool
50 mm mineral wool
Screen panel
13 mm gypsum panel with plastic foil
(In Fig. a): Inside
b) Foam plastic
c) portion not supplemented; supplemented portion)

Measuring conditions:
Could cover: Overcast
Outdoor temperature; ± 0°C
Indoor air temperature: + 23°C
Wind conditions: Calm
$p_i - p_u$: - 8 Pa

a) Horizontal section of outside wall. The mineral wool panels are badly fitted and badly filling in the wall.
b) The outside wall has supplementary plastic foam insulation.
c) Thermogram of wall portion where surface portion at right corresponds to additionally insulated portion according to b). Surface portion at left has not been supplemented.
d) $t_{ref}$ = + 22°C
$\Delta I$ = - 0.9 isotherm units
$\Delta t$ = 1.5°C
v = 0 m/s.



c)



d)

# 8. SHORTCOMINGS IN THE INSULATION AND TIGHTNESS PERFORMANCE

## 8.1. Preconditions

The existing reports on construction deficiencies are based on field studies with heat camera during the period 1972 - 1976. The studies have focused on functional control of the heat insulation and air tightness of guildings.

Among the total number of investigated projects, some 400, approximately 150 projects have been studied more closely in repect to systematic deficiencies in insulation anu tightness execution. The reported projects have been the objects of thermography studies for the following reasons:

1. Complaints concerning unsatisfactory indoor climate (disturbing cold drafts and radiation drafts) from the residents, and claims that the energy consumption has been abnormally high.

2. Inspection due to drectives in the construction documentations, or, the desire of the builder or entrepeneur for testing and control during the construction period or at the time of the final inspection.

The selected projects are geographically distributed over the entire country with emphasis on central Sweden. In the selection of projects, consideration was given to the construction type, the material selection, and the work methods. In general, the measurements have been performed in buildings 1 - 5 years of age.

The investigated projects have been selected from available material without claims on statistically correct selection principle. The material cannot be said to present a correct impression of the frequency of deficiencies in buildings in general. On the other hand, the reported material may give an indication of occurring types of deficiencies and of the construction portions and construction types that are most commonly displaying deficiencies.

In those cases, where the construction projects in question have been divided into various construction stages, this presentation includes only those houses or apartments included in the stage that was studied. The existing material includes some 3,000 residences that have been investigated, located in single and multiple dwellings. The number of single family dwellings constitutes a slightly larger proportion, approx. 65%. Normally, the investigated apartments have constituted some 15-20% of the total number of apartments in the construction phase. The report does not include individual apartments.

The following, simplified principles have been followed in the evaluatior of

whether an observed deficiency in a certain portion of the construction would be judged acceptable or not:

Deficiency has been noted if

- the cooling of the surface portion has been estimated as corresponding to approx. 40% of the prescribed insulation thickness and the size of the cooled surface is more than approx. 20% of the construction component in a certain space unit;
- the speed of inwardly leaking air has been measured as being higher than 0.3 - 0.4 m/s at a normal pressure difference of approx. 5 Pa throughout the construction and if the leakage extends to more than 30% of the running footage of joint or connection;
- the measured air speed at the leakage point is more than 1 - 2 m/s at a normal pressure difference of 5 Pa. If there are convective air movements in the construction, the evaluation has been made with consideration of the demands for both good energy management and good indoor climate, as well as the risk of condensation and damage.

A nomogram illustrating the condensation risk at different temperatures and levels of relative humidity is shown in FIGURE 127.

The effect of cold bridges due to construction technology and of underdimensioned insulation in walls and beam tiers has not been separately recorded.

## 8.2. Identification of construction errors

The material is presented in the form of a tabular summary, where the following information is given in the respective table:

- Type of construction.
- Number of projects included in the material.
- Total number single family dwellings and/or apartments in multiple dwellings included in the projects.
- The number of investigated single dwellings and/or apartments in multiple dwellings with the type of construction investigated.
- The proportion of single dwellings and apartment units in multiple dwellings displaying deficient and/or acceptable insulation or tightness function of the construction component in question.

When reporting the observed deficiencies in the heat insulation and air tightness functions of the building, each building portion has been treated separately according to following:

Floor joist tier with connections;
Intermediate beam tiers with connections;
Beam tier for attic (truss portion) with connections;
Insulated roof (slanting roof);
Outside walls.

Brief comments concerning the types of errors observed, etc. in the various building components will be given in the following section.

Floor joist tier, type bb 1. Concrete slab on ground with studded floor with mineral wool insulation placed on top of the concrete alab.

Deficient function for heat insulation and tightness is relatively frequent, particularly in areas close to outside wall. The defects are mainly due to unsatisfactory filling and fitting of the insulation material at the edges of the joist tier. Air leakages through connections at the joists are frequent. The cold outdoor air can propagate in the joist tier and leak into the residential areas. Efficient and careful sealing of the joist tier and good filling with the heat insulation material in the compartments between the joists are required, particularly in the outer edge areas, if the function is to be fully satisfactory. This decreases the effect of possibly occurring cold bridges.

(Top to bottom designations in figure: Subflooring
Mineral wool
Joist insulation)

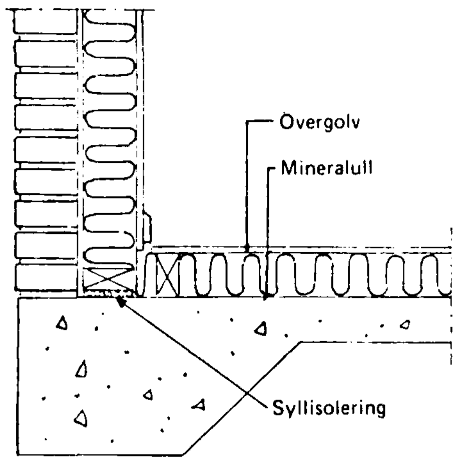



TABLE 6: Total number of houses/apartments in investigated projects.
Single dwellings: 1,365. Multiple dwellings: 20/291.

| TYPE OF BUILDING | NUMBER | | PROPORTION, % | | | |
|---|---|---|---|---|---|---|
| | Projects | Investigated houses / apts | Houses/apts with acceptable function | | Houses/apts with deficient function | |
| | | | Joist tiers | Joist conn. | Joist tiers | Joist conn. |
| Single dwellings | 10 | 240 | 38 | 26 | 62 | 74 |
| Multiple dwellings | 5 | 14/81 | 29/38 | 0/0 | 71/62 | 100/100 |

Floor joist tier, type bb 2. Concrete slab on ground with mineral wool insulation placed under the concrete slab.

The deficiencies observed here are due either to deficient joist sealing resulting in direct air leakage into the residential area, or to uneven function of the insulation of the outside beam. These conditions frequently cause abnormally strong cooling of portions of floors close to outside walls. Inward air leakage in these portions usually causes great local temperature variations with distinct borderlines in the thermogram. Uneven function of the outside beam insulation causes lesser temperature variations, usually with diffuse borderlines of the cooled surfaces. However, this construction type gives a lower floor temperature than does construction type bb 1.

(Top to bottom in figure: Brick facing; Mineral wool; Gypsum panel; Joist insultaion; Ground insulation).

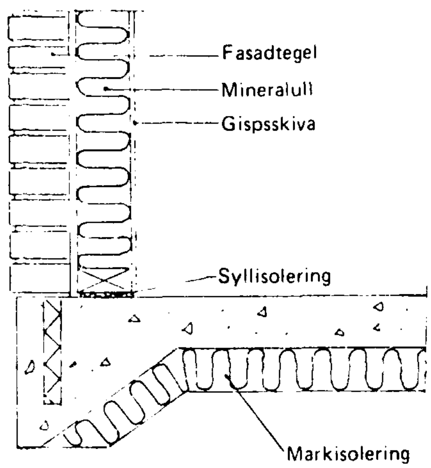



TABLE 7: Total number of houses/apartments in the investigated projects. Single dwellings: 205. Multiple dwellings: 7/165.

| TYPE OF BUILDING | NUMBER | | PROPORTION, % | | | |
|---|---|---|---|---|---|---|
| | Projects | Investigated houses / apts | Houses/apts with acceptable function Joist tiers | Houses/apts with acceptable function Joist conn. | Houses/apts with deficient function Joist tiers | Houses/apts with deficient function Joist conn. |
| Single dwellings | 6 | 60 | 100 | 58 | 0 | 42 |
| Multiple dwellings | 4 | 4/33 | 100/100 | 75/64 | 0/0 | 25/36 |

Floor joist tier, type bb 3. Tier on ground with light clinker insulation edge beam of light clinker and surface stabilized light clinker).

The deficiencies observed in this construction type are mainly inward air leakages due to insufficient function of the joist sealing. The cooled portions are generally limited to the edge portions of the joist tier, in connection with the tier edge proper. Otherwise, the insulation function of the joist tier is not affected.

From the point of view of sealing, the construction depends on careful surface leveling at the edges of the joist tier as well as an efficient joint sealing system. As construction type bb 2, this construction type gives a slightly lower floor temperature than construction type bb 1.

(Top to bottom in figure: Brick facing; Wind barrier; Insulation; Gypsum panels; Joist; Joist sealing.)

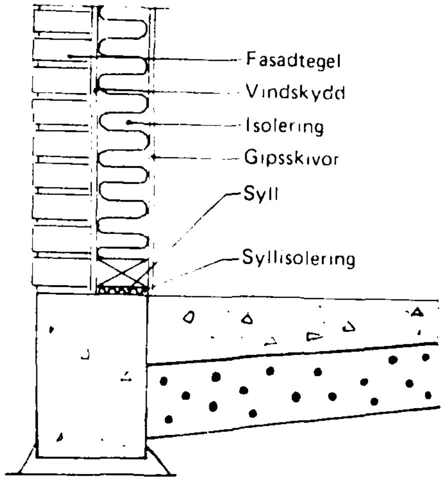



TABLE 8: Total number of houses/apartments in the investigated projects. Single dwellings: 1,758. Multiple dwellings: 55/997.

| TYPE OF BUILDING | NUMBER | | PROPORTION, % | | | |
|---|---|---|---|---|---|---|
| | Projects | Investigated houses / apts. | Houses/apts with acceptable function | | Houses/apts with deficient function | |
| | | | Joist tiers | Joist conn. | Joist tiers | Joist conn. |
| Single dwellings | 36 | 293 | 100 | 48 | 0 | 52 |
| Multiple dwellings | 19 | 33/198 | 100/100 | 36/24 | 0/0 | 64/76 |

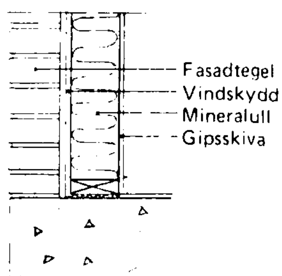
Studded wall of wood with mineral wool insulation and exterior brick facing or, alternatively, wood panels yv 1.

Defects observed in the outside walls have usually been related to air leakage through fittings between different building components. This may affect the heat insulation function in wall portions close to the leakage points insofar that cold outdoor air is propagated in the construction, resulting in convenctive air movements and decreased heat resistance. For this reason, the defects are, as a rule, localized to portions close to joints and connections (mainly beam tier connections). The result would indicate that the insulation function of the wall is better throughout when a high quality mineral wool is used (A quality). The extent of insulation deficiencies in unbroken wall portions seems to be limited.

In constructions with (pressure equalizing) air space between the heat insulation material and the facing, it has been stated that the risk of air leakage through the construction is less than if the air space has been eliminated. In cases of wind load towards the facade, the effect of local deficiencies in the sealing layer of the wall is greater if the pressure equalizing air space is missing than if it is there. The investigations have demonstrated the importaince of an intact sealing layer.

Furthermore, it has been found that vertical air spaces, due to unsatisfactorily fitted insulation material at the studes, electrical conduits, etc., may have a significant influence on the heat insulation function, since air movements occur in the air spaces.

In the case of pre-fabricated houses, the heat insulation of the outside walls is noticeably better, particularly in respect to air-tightness, than is the case in on-site built houses.




(Top to bottom in figure: Brick facing; Wind barrier; Mineral wool; Gypsum panel.)

TABLE 9: Total number of houses/apartments in the investigated projects. Single dwellings: 3,110. Multiple dwellings: 86/1,558.

| TYPE OF BUILDING | NUMBER | | PROPORTION, % | | | |
|---|---|---|---|---|---|---|
| | Projects | Investigated houses / apts | Houses/apts with acceptable function | | Houses/apts with deficient function | |
| | | | Beam tiers | Beam conn. | Beam tiers | Beam conn. |
| Single dwellings | 74 | 659 | 87 | 49 | 13 | 51 |
| Multiple dwellings | 27 | 46/280 | 61/59 | 39/3[illegible] | 39/41 | 61/62 |

Intermediate beam tier of light concrete, mb 1.

The deficiencies in conjunction with this constructop type are usually related to leaking connections at the edge of the beam tier, frequently resulting in air leakage into the residential area. Otherwise, the beam tier functions satisfactorily. When the joist sealing is fully functional, the effect of the cold bridge is relatively insignificant.

(Top to bottom in the figure: Wind barrier; Mineral wool; Moisture barrier; Gypsum panel.)

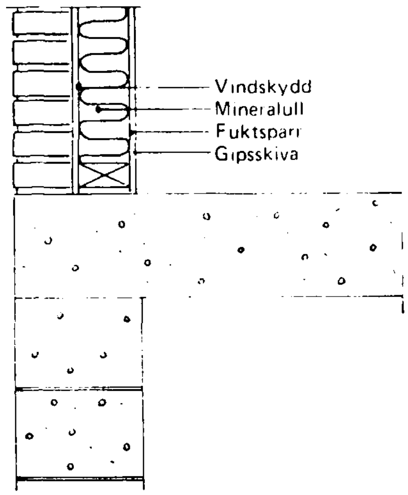



TABLE 10: Total number of houses/apartments in the investigated projects. Single dwellings: 41. Multiple dwellings: 0.

| TYPE OF BUILDING | NUMBER | PROPORTION, % | | | | |
|---|---|---|---|---|---|---|
| | Projects | Investigated houses / apts | Houses/apts with acceptable function | | Houses/apts with deficient function | |
| | | | Beam tiers | Beam conn. | Beam tiers | Beam conn. |
| Single dwellings | 6 | 41 | 100 | 17 | 0 | 83 |
| Multiple dwellings | - | - | - | - | - | - |

Intermediate beam tier of wood, mb 2, partially filled with heat insulation material.

The construction is predominantly found in single family dwellings, which, for that reason, constitute the major proportion of the projects included in the investigation.

Generally, the deficiencies observed in this construction type are related to leakages in the connections between beam tier and ouside wall, or to insufficient filling of insulation material at the edge of the beam tier, resulting in air leakage into the construction. In this manner, relatively vast surfaces in ceiling and floor portions may be cooled. The air leaking into the beam tier may also propagate in intermediate partitions and leak into the residential area through joints and connections (electrical outlets).

The results indicate a relatively high frequency of deficiencies. One should observe the importance of the insulation material filling the entire space in the beam tier at the edges, approx. 1 m from the outside wall.

(Top to bottom in figure: Subflooring; Air space; Mineral wool; Screen panel; Gypsum panel.)

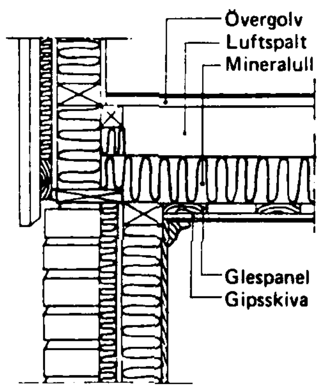



TABLE 11: Total number of houses/apartments in the investigated projects. Single dwellings: 1,906. Multiple dwellings: 0.

| TYPE OF BUILDING | NUMBER | | PROPORTION, % | | | |
|---|---|---|---|---|---|---|
| | Projects | Investigated houses / apts | Houses/apts with acceptable function | | Houses/apts with deficient function | |
| | | | Beam tier | Beam conn. | Beam tier | Beam conn. |
| Single dwellings | 37 | 380 | 21 | 10 | 79 | 90 |
| Multiple dwellings | - | - | - | - | - | - |

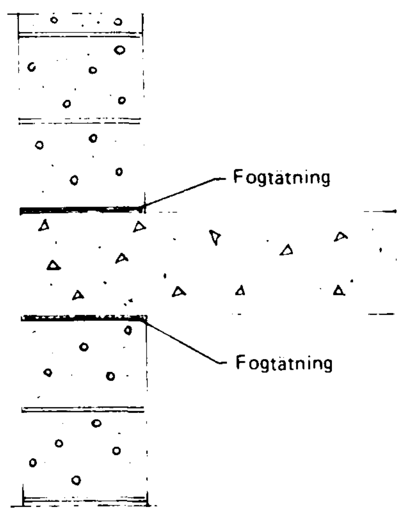
Intermediate beam tier of concrete, mb 3.

The investigation material is dominated by beam tiers in multiple dwellings.

Inward air leakage at the beam tier connections is relatively common in this type of construction. The air leakage affects the floor and ceiling temperatures in the vicinity of the leakage point.

For reasons of construction, there are no defects due to insufficient insulation. Relatively low floor temperatures may be obtained when the beam tier is located above an unheated basement area, this due to the low heat resistance of the beam tier.

In this type of construction there is a certain cold bridge effect at the beam tier connections.




(In the figure: Joint sealing.)

TABLE 12: Total number of houses/apartments in the investigated projects. Single dwellings: 0. Multiple dwellings: 33/805.

| TYPE OF BUILDING | NUMBER | | PROPORTION, % | | | |
|---|---|---|---|---|---|---|
| | Projects | Investigated houses / apts. | Houses/apts with acceptable function Beam tier | Beam conn. | Houses/apts with Deficient function Beam tier | Beam conn. |
| Single dwellings | - | - | - | - | - | - |
| Multiple dwellings | 14 | 19/155 | 100/100 | 21/21 | 0/0 | 70/79 |

Beam tier for attic, of wood, vb 1, in conjunction with saddle roof with mineral wool insulation and screen panel construction

The observed deficiencies are located partially at the soffit connection, partially to portions in the roof beams connected to truss and construction wood.

At the soffit connection, there is usually a lack of continuity of the insulation materials in wall and beam tier. Frequently, the filling of insulation material is insufficient in the compartments provided for this purpose. The continuity of the outer and inner sealing layers in the construction is frequently overlooked. The result is an aeration in the construction which may, in turn, cause a decrease of the heat resistance as well as an inward air leakage into the residential area. The air may also propagate in the channels formed in the screen panel construction, resulting in cooled surfaces relatively far into the beam tier.

Due to frequently unsatisfactory fitting of the insulation material against truss and rafters, insulation defects in the attic beam tier are relatively common. When the pressure conditions vary throughout the construction, the air in the attic area may penetrate cracks and hollows and propagate in the abovementioned channels.

The investigation has shown that in general, a placement of the diffusion barrier between the screen panel and the ceiling gives greater possibilities for the air to propagate throughout the construction than if the diffusion barrier is placed tightly against the insulation material.

Further, it has been found that the format and quality of the insulation material has a noticeable effect on the insulation and tightness function of the construction. When insulation materials with high penetrability for air and low mineral wool quality have been used, it has been found that filling and fitting of the insulation material requires more careful execution in order to obtain satisfactory insulation and tighness function.

Electrical installations in the beam tier often make it difficult to execute the work well and may thus cause deficiencies in the insulation and sealing layers of the construction.

(Top to bottom in the figure: Mineral wool
Screen panel
Diffusion barrier
Gypsum panel.)

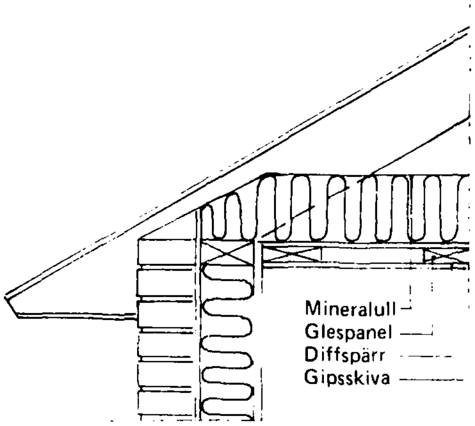



TABLE 13: Total number of houses/apartments in the investigated projects. Single dwellings: 1,352. Multiple dwellings: 29/553.

| TYPE OF BUILDING | NUMBER | | PROPORTION, % | | | |
|---|---|---|---|---|---|---|
| | Projects | Investigated houses / apts | Houses/apts with acceptable function | | Houses/apts with deficient function | |
| | | | Beam tier | Beam conn. | Beam tier | Beam conn. |
| Single dwellings | 47 | 743 | 30 | 27 | 70 | 73 |
| Multiple dwellings | 12 | 18/106[?] | 61/55 | 61/55 | 39/45 | 39/45 |

Beam tier for attic, of wood, vb 2, with insulated sloping roof portion (finished attic).

This construction is mainly found in single family dwellings and in low-rise developments.

The deficiencies observed are localized to the soffic connections (see beam tier for attic, vb 1), upright member wall connections to the beam tiers, and insulated sloping roof portions.

At the connection of the upright member wall to the intermediate beam tier, the fitting of insulation material to wooden beams is frequently insufficient and the filling is often uneven in the compartments for insulation material. Frequently, the insulation is omitted in beam tiers between the heated residential areas on the upper and lower floors, or, it consists merely of a thin (approx. 5 cm) mineral wool insulation (sound insulation). The continuity of sealing layers in these connections if frequently unsatisfactory. These conditions may lead to air leakage both into the residential area and into the beam tier (aeration), thereby causing vast cooled surface portions in the beam tier. Leakages can also affect the insulation function of the upright member wall due to inward air leakage in this construction.

The connections of the sloping roof to the upright member wall and the attic beam tier have been found to be sensitive from the standpoint of insulation and tightness.

The insulation function of the sloping roof is frequently deficient, partly because the mineral wool insulation does not touch the inner (warm) surface panel, partly due to deficiencies in the sealing layer. This frequently causes the cold outdoor air to penetrate into existing hollows, and shortcircuit the effect of the heat insulation. The investigations have also shown that insulation material may touch the outside roof, thus preventing the necessary aeration of the construction.

In certain cases, moisture and rotting damages have been observed. The use of a spacing panel between the insulation material and the outside roof, simultaneously functioning as a wind barrier, has proven to give better results.

In the cases of horizontal attic beam tiers, the deficiencies are predominantly localized to the connection of the beam tier to the gable walls, due partly to insufficient filling of the insulation material in contact with the studs, partly to deficiencies in the sealing layer of the construction. As has previously been pointed out, this may also affect the interior of the beam tier in the case of screen panel construction.

(Top to bootom in figure:
Mineral wool mat
Mineral wool panel
Plastic foil
Gypsum panel
Wind barrier
Mineral wool
Plastic foil
Gypsum panel
Mineral wool mat
Mineral wool panel
Plastic foil
Ceiling facing.

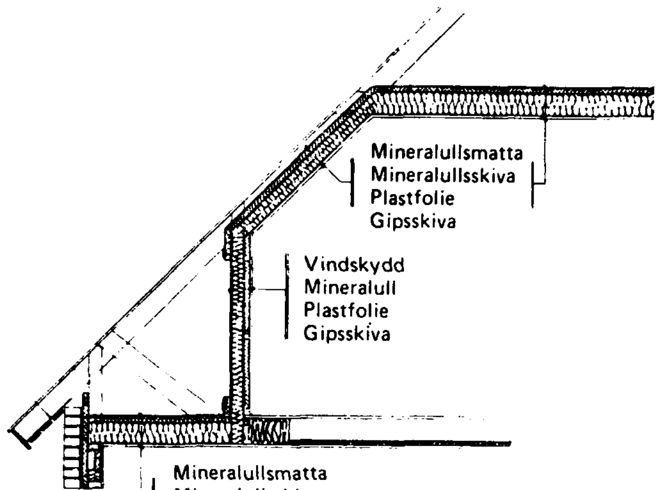



TABLE 14: Total number of houses/apartments in the investigated projects. Single dwellings: 1,077. Multiple dwellings: 0.

| TYPE OF BUILDING | NUMBER | | PROPORTION, % | | | |
|---|---|---|---|---|---|---|
| | Projects | Investigated houses / apts | Houses/apts with acceptable function Beam tier | Houses/apts with acceptable function Beam conn. | Houses/apts with Deficient function Beam tier | Houses/apts with Deficient function Beam conn. |
| Single dwellings | 20 | 246 | 16 | 11 | 84 | 89 |
| Multiple dwellings | - | - | - | - | - | - |

Beam tier for attic, of wood with mineral wool insulation, flat roofs, vb 3.

The investigations have shown that deficiencies occur with relaitvely high frequency at the soffit connection, particularly on the long sides of the house, where the insulation material is frequently fitted in an unsatisfactory manner, so that the filling is insufficient. There are also frequent deficiencies in respect to the insulation material filling of the rafters, e.g. at upright members and other construction details.

When the wind barrier is insufficient, the cold outside air can penetrate into the construction, into existing hollows, and can propagate in the beam tier, particularly in the case of screen panel construction types.

Inadequate execution of insulation and sealing in the attic beam tier may also cause cold air to leak inward and propagate in inside walls.

(Top to bottom in figure: Mineral wool; Screen panel; Diffusion barrier; Gypsum panel.)

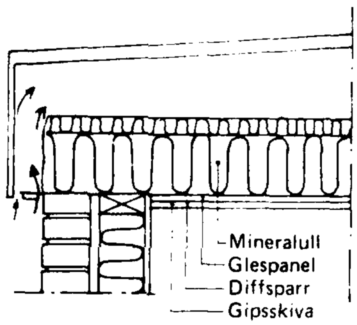



TABLE 15: Total number of houses/apartments in the investigated projects. Single dwellings: 703. Multiple dwellings: 0.

| TYPE OF BUILDING | NUMBER | | PROPORTION, % | | | |
|---|---|---|---|---|---|---|
| | Projects | Investigated houses / apts. | Houses/apts with acceptable function | | Houses/apts with Deficient function | |
| | | | Beam tier | Beam conn. | Beam tier | Beam conn. |
| Single dwelling | 15 | 155 | 48 | 40 | 52 | 60 |
| Multiple dwellings | - | - | - | - | - | - |

Beam tier for attic, of concrete with mineral wool insulation, flat roofs, vb 4.

The construction is predominantly found in multiple dwellings. The investigations have shown that the deficiencies observed here are usually located at the edge portions of the attic beam tier. The fitting of the insulation material is frequently inadequate, resulting in relatively severe cold bridge effect. Certain deficiencies have also been observed in the connections of ventilation ducts and installations on the attic beam tier, due to difficulties in fitting the insulation material in a satisfactory manner.

Air leakage through connections of beam tiers to outside walls seem to occur to a certain extent, when the outside wall and the beam tiers are not of the same material.

(Text in the figure: Mineral wool.)

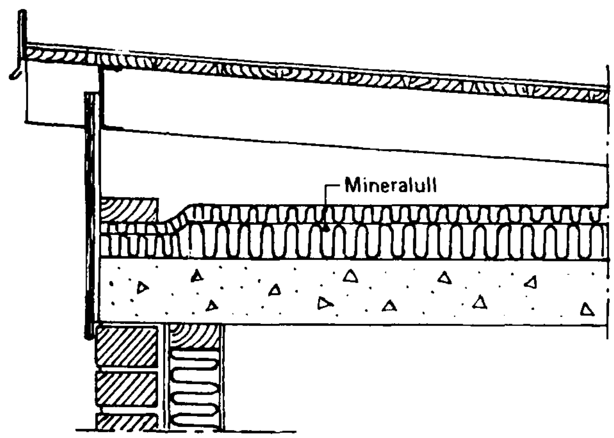



FIGURE 16: Total number of houses/apartments in the investigated projects. S' gle dwellings: 81. Multiple dwellings: 33/778.

| TYPE OF BUILDING | NUMBER | | PROPORTION, % | | | |
|---|---|---|---|---|---|---|
| | Projects | Investigated houses / apts. | Houses/apts with acceptable function Beam tier | Beam conn. | Houses/apts with Deficient function Beam tier | Beam conn. |
| Single dwellings | 3 | 18 | 22 | 17 | 78 | 83 |
| Multiple dwellings | 5 | 23/170 | 52/54 | 52/54 | 48/46 | 48/46 |

# 9. EXPERIENCES

## 9.1. Experiences of construction technology

The investigations have shown that deficiencies in the insulation and tightness execution are very common, even in newly built houses. Construction design and material selection as well as workmanship have the greates importance. Generally, these factors are related. The simplified explanation that errors are due to carelessness in the construction work only, is generally unfounded. The observed deficiencies have often been of a systematic character. The have reappeared regularly in conjunction with certain construction types and materials.

Certain construction components in a building are more apt to be inadequate than others. Such exposed parts are the connection points of beam tiers and soffits, certain insulated beam tier and sloping roof portions, and joints between different building parts.

Air leakage through joints and connections as well as inadequate filling of insulation material in the portions marked in FIGURE 123 a) - b) seem to be the most frequent types of deficiencies. Such errors can cause an unsatisfactory temperature distribution and unplasant air movements (drafts) in the residential areas as well as locally low surface temperatures on construction surfaces, with risk for condensation and dirt deposits. Deficiencies in the inner or outer sealing layers of the construction cause risk for air penetration of the construction and may cause accumulation of moisture.

New, material-saving construction types have frequently been found to be very sensitive from the standpoints of air tightness and heating, resulting in difficulties to maintain sufficiently high indoor temperatures, particularly on windy days. Leakages in so called multiple layer constructions may frequently "short-circuit" large portions of insulated portions, resulting in cooled surface portions.

The investigations have also shown that prefabricated houses generally are better made in respect to insulation and tightness than are houses built on site. There are, however, variations in both categories.

The possibility to control the insulation and tightness performance by means of the heat camera has clearly had a strongly preventive effect which also extends to construction work not directly subjected to testing.

The results from the investigated objects, some 2,000 single family dwellings, approx. 1,600 apartments in multi-unit residential buildings, and some 50 other buildings (office, hospital, and industrial buildings) which have been partially reported in section 8.2. can be summarized as showing that

- certain insulation and sealing materials are less than adequate from the standpoints of insulation and tightness,

FIGURE 123: Single dwellings and multiple dwellings: the construction details particularly sensitive from the standpoints of heat insulation and tighness have been indicated.

a) Single dwelling

Clockwise from top, right side of figure:

Attic beam tier; Rafter tier (sloping roof); Intermediate beam tier for attic space; Connection of window portions to outside wall; Connection of upright members to intermediate beam tiers; Floor joist tier connection to outside wall; Soffit; Connection of upright member to rafters (sloping roof); Connection of rafters to attic beam tier.

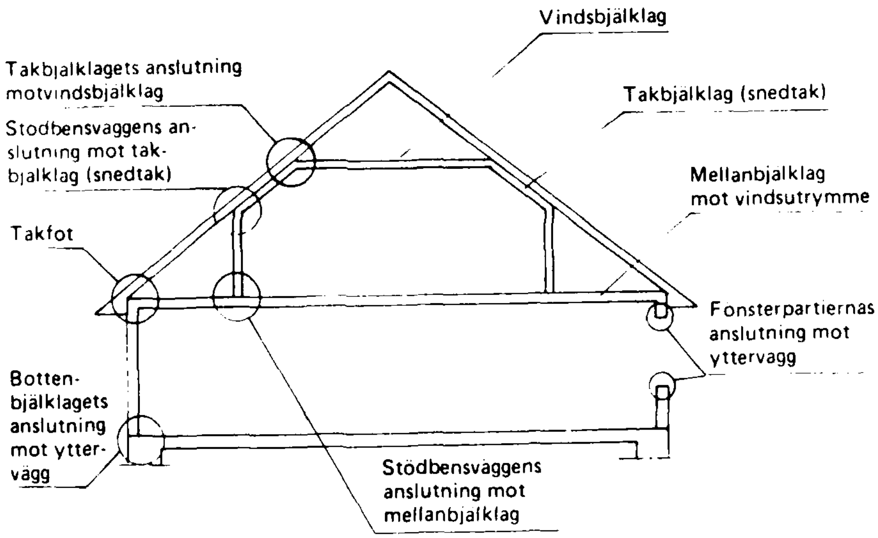
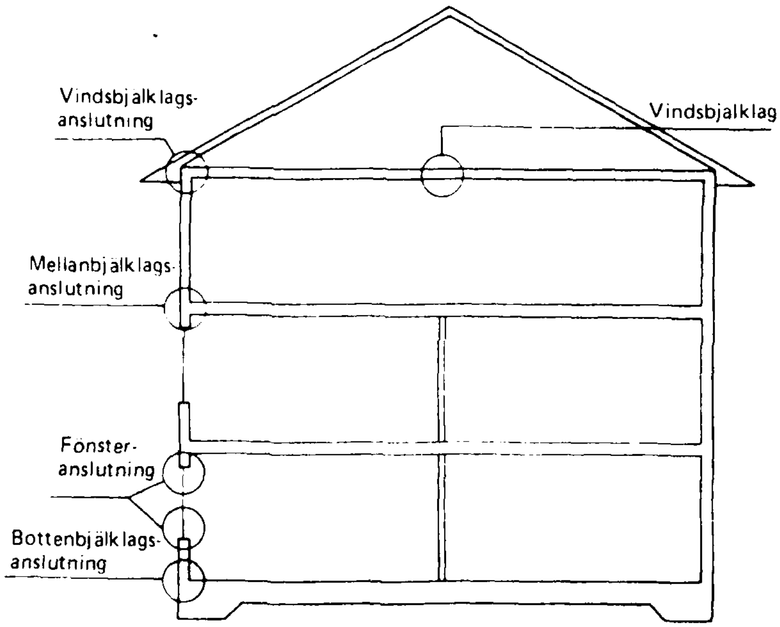


FIGURE 123 (Continued):

b) Multiple dwelling

Top to bottom, left side of figure:
Connection of attic beam tier; Connection of intermediate beam tier; Window connections; Connection of floor joist tier.

Top right in figure:
Attic beam tier.



- certain construction types are very sensitive from the standpoint of tightness,

- certain manners of execution have proven inappropriate from the standpoints of insulation and tightness,

- the dominating type of deficiency is air leakage through joints and connections,

- air leakage into the construction at certain critical points (e.g. the soffit area) causing convective air movements in the construction is quite common,

- for approx. 80% of the objects investigated, action has been recommended.

The resulting action is related to the following factors:

- the construction method of the building,

- material selection and knowledge of materials,

- existing wiring and other installations, e.g. electrical wiring and pipe penetrations in the construction,

- work methods and workmanship.

9.1.1. Construction

As has been previously mentioned, more stringent requirements on heat insulation and tightness of buildings have been formulated in Svensk Byggnorm [Swedish Construction Standards], 1975, chapter 33:4 [16].

Naturally, a construction object is to be designed so that it is possible to ascertain good execution of its heat insulation and tightness even with the current work methods and rapid pace. It would seem essential that well tested construction types will be increasingly frequently used in order to create satisfactory conditions in respect to both energy consumption and comfort.

Certain construction types have been found to have a high frequency of deficiencies, e.g. screen panel constructions. When screen panels have been used in beam tiers and walls (upright member walls), the diffusion barrier has been found between the screen panel and the surface layer. The diffusion barrier should be palced in the layer closest to the heat insulation material. This placement decreases the risk of air leakage into the construction and air propagation in the channels formed between the screen panels. The investigations have shown that if the diffusion barrier is placed in this manner, the function of the heat insulation improves. However, this may require some additional work, since supplementary sealing will be required, e.g. at electrical installations.

At load carrying inside walls (upright member walls) in single family dwellings with finished attics, there is frequantly an air leakage into the wall construction at the corners, particularly if there is a screen panel at the inside of the heat insulation. For this construction type, it is essential to have fully satisfa...

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sealing at the connections with gable walls, roof, and beam tiers. On the outside, upright member walls should be provided with a satisfactory wind barrier. Connections to beam tiers must be executed with utmost care. Deficiencies also occyr where the upright member wall is connected to a sloping roof, Here, there are difficulties in obtaining fully satisfactory air tightness and filling of the heat insulation material in the construction.

Soffit areas are very sensitive in respect to insulation and tightness. Here, it is often difficult to obtain continuity of insulation material and sealing layers. Various executions of this construction detail have been found to give great variations in the insulation and tightness function. Special solutions in the form of prefabricated soffit components have been found to simplify the execution and generally improve the function.

### 9.1.2. Materials

High quality insulation materials are available at the current time. The heat insulation characteristics of these are relatively well known. A realtively extensive testing and control activity is undertaken by means of laboratory measurements, e.g. VIM control. The function of a construction is determined by the characteristics of the individual materials. It is essential that the materials included in the total construction are compatible, so that the desired function of the construction will be obtained and maintained even under practical conditions.

The investigation has shown that mineral wool insulation of higher quality (A quality) gives better results than lower grades. Materials of A quality also seem to provide better filling of the construction details. When a lower grade of material is used (B quality), it is generally necessary to exercise more care in the execution of the work. Measurements performed on lightweight roof truss constructions insulated with mineral wool of both B and A quality have shown remarkable differences in the results, in respect to both insulation and tightness.

Insulation with flocculated mineral wool is used both form beam tiers (the type is approved by the national planning office) and for supplementary insulation in order to improve insulation and tightness function of beam tiers. The material is realively easy to apply, provides good filling against construction details, and has a good insulation value, provided that there is a fully satisfactory sealing layer. However, the experience of this is relatively limited in the present investigation material.

Carbamide resin foam is most appropriately used as supplementary insulation in walls and beam tiers where the original insulation consists of other types of material. The results from performed measurements shows that fully satisfactory insulation and tightness fuction will be obtained, provided that there is a careful control of material and workmanship. Severe damages have been found in cases where the material has not had the proper composition or when the injection was not properly executed (insufficiently cleaned spraying equipment). Moisture damage of construction components as well as shrinkage of insulation material have been found in such cases, see FIGURE 124.

Cutter shavings as insulation material in outside walls and beam tiers are found predominantly in older buildings. It has been found in the studies

that the material has become somewhat compressed. The insulation value of this material is relatively low. The degree of compression and the tightness function have been found to be satisfactory, and the material has thus been found to be valueable for supplementary insulation, e.g. in attic beam tiers. The investigations include a number of projects where this usage has had good results.

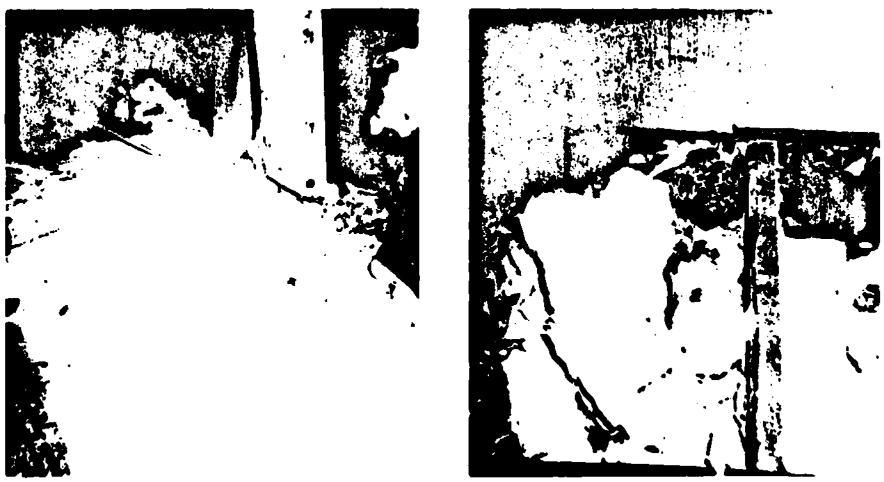
Lower grade material has a higher degree of air permeability, and is thus more dependent on a fully satisfactory sealing layer, a fact that is frequently overlooked, e.g. at soffit connections.

The existence of specific insulation products, e.g. "rafter panel" and "wing panels" can facilitate the work significantly. Thereby, the risk of undesirable air spaces and channels in the construction is also decreased. Development and use of such specialty products improves the potential for good execution and performance.

FIGURE 124: Opening of beam tier portion one year after injection of plastic foam. Two different qualities have been used.

a) Satisfactory foam material filling.

b) Inadequate filling of foam materisl (shrinkage and crack formation.



In the case of heavy construction (light concrete and concrete), one will generally obtain a relatively tight construction. There are certain problems in respect to joints and connections between various building components with different materials. In these locations, there is frequently a certain penetration, resulting in leakage of air and moisture. This is due to the different characteristics of the materials, which will expand at different rates under climatic variations, thus frequently causing cracks.

Concerning concrete walls with exterior insulation of mineral wool the

investigations have shown that the quality of the insulation material determines the insulation function. In order to obtain satisfactory function, high quality mineral wool is required, so that the material can be glued or poured against the concrete wall.

In constructions of light concrete, the air tighness is often relatively good. However, the investigations show that significant crack formations may occur, both at joints and in the blocks proper.

### 9.1.3. Sealing layers

The function of inner and outer sealing layers is essential for the total insulation and tightness function of the construction. Various sealing layers have been tested in conjunction with the investigation.

The most common wind barrier, sheathing paper placed on the outside of the insulation material, has sometimes be found not to function satisfactorily. When building portions have been opened, it has been found that the damages to the sheathing frequently have the form of tears, inadequate fastening, and insufficient overlapping. When air movements have been measured in wall constructions where deficiencies have been observed, the sheathing paper occasionally seems to cause a so-called pump effect, e.g. air flows in existing spaces and hollows under varying wind pressures on the construction. When the sheathing paper is placed inside the outer insulation layer, e.g. in the type called "west coast wall", no such effect has been observed.

Wind barriers consisting of wood fiber panels (type masonite) do not seem to function satisfactoryily, due to difficulties in creating tight joints both between the panels and against the studs, particularly if the material has been exposed to moisture. Taping of the joints has not given the desired effect.

Wind barriers of asphalt impregnated wood fiber panels ("asphaboard" type) generally seam to give satisfactory results. Here, as well, it should be emphasized that the material must be closely attached to the studding. If the material has been exposed to moisture, supplementary nailing of the wood fiber panels may be required.

Studies have also been undertaken with the purpose of claifying the wind barrier effect of mineral wool panels with high density with otherwise varying executions of the heat insulation. The results from the measurements indicate that there are no objections to the heat insulation function of constructions with such wind barriers, provided the insulation material is tightly attached to the studding and the panels are well fitted to each other. When applied in accordance with the directions from the manufacturers, the wind barrier function seems to be equal to corresponding function of other wind protection materials. The measurements show a relatively high frequency of deficiencies in cases where the assembly directives have not been followed.

The unfavorable effect of deficiencies in the outer wind barrier is decreased if the inner sealing layer is fully intact. Generally, satisfactory function is provided by a diffusion barrier (plastic foil) overlapping 20 cm at all joints, corner portions, etc. A plastic coated wall material does not seem to give the same effect due to the fact that the joints between the panels may not always be tight.

Particular attention should be given to diffusion dealing in the roofing area, the connection of the rafters to the gable walls, etc. In these areas, deficient sealing may cause leakage of warm air into the construction, which means a risk of moisture in these areas. Moisture damage in combination with rotting and molding damages has been observed in conjunction with such deficiencies.

### 9.1.4. Joint sealing

Air leakage through joints and connections occurs frequently. When this construction detail is designed, it is vital that the width of the joint is sufficient, so that the joint can be effectively sealed. Experience has shown that a widht of 15 $\pm$ 5 mm is appropriate.

In the sealing of joints, the material selection is of major importance for the tightness function. Certain types of materials are less suitable in respect to both function and application. If caulking strips of mineral wool are used, it is required that they are folded when applied to the joinst and also that the filling is sufficient (usually 2 - 4 strips), see FIGURE 97. The best tightness function seems to be obtained when using polyurethane foam, joint sealing strips of EPDM rubber, and Gullfiber brand "Fogfibersystem", see FIGURES 99-101.

### 9.1.5. Installations

Electrical installations and penetrations of construction frequently cause problems in respect to insulation and tightness function. Air movements frequently occur, both in the conduits for electrical installations, and in the channels formed between piping details and insulation material. Electrical wiring conduits in conjunction with soffit areas are particularly sensitive. In those cases when electrical installations are placed in the inside walls rather than in the outside walls, the insulation and tightness function is usually better.

### 9.1.6. Workmanship

Unskilled personnel is sometimes used for application of sheathing and joint sealing material. This frequently results in inadequate workmanship due to lack of knowledge of the function and characteristics of the marious materials. Those who perform the insulation work must be knowledgeable about the "sensitive" portions of the construction as well as the function of the various material layers in the construction. Training and information are important factors.

When the insulation work is done on a construction site, it is essential to obtain good filling of insulation material, both against the studs and against hte "warm side" of the wall. If there are air spaces or channels in these areas, air leakage into the construction may occur, whereby the insulation function deteriorates due to convective air flows in the construction. If, in addition, there are deficiencies in the diffusion barrier, a direct air leakage into the residential area may occur. The insulation function of outside walls appears to be improved if higher grade insulation material (A quality) is selected and if insulation panels are used which fit into the compartments between the studs in the construction. Small pieces of the heat insulation material usually provide inadequate filling, resulting in undesirable air spaces and channels. Heat insu-

lation material applied in several layers in the wall will frequently compensate for local deficiencies in the workmanship.

In conjunction with field measurements it has been noticed that insulation of beam tiers is usually performed from the center of the beam tier towards the connections of the beam tiers. As a consequence the fitting of the insulation material and the wind barrier will often be inadequately executed at the soffit and at the edges of the beam tier.

## 9.2. Recommendations concerning measurement techniques

### 9.2.1. Preparations

Before thermography of a building is performed, information should be gathered concerning the construction design of the building, e.g. drawings and technical specifications. Furthermore, external conditions should be recorded, such as air temperatures, wind conditions, and radiation conditions.

Thermography can be performed when the stated requrements on the measuring conditions are fulfilled. Usually, the measurements are performed from the inside of a building portion, in order to eliminate e.g. disturbing influences from outside climate factors. Measurements may be performed outdoors, e.g. in the case of orientation measurements over larger facade surfaces. An outdoor measurement may be advantageous when the heat insulation and air tightness are inadequate or when there is a positive indoor pressure.

At the occasion of the thermography, the following are to be observed and determined at the measurement location:

- Maximum and minimum temperature during 24 hours prior to the measurement, e.g. by means of a "max/min" thermometer or information from the SMHI [Sweden's Meteorological and Hydrographic Institute].

- Sun conditions during 12 hours prior to the measurement.

- Wind conditions (wind direction and force) on the measuring occasion.

- The orientation of the building as well as surrounding buildings and terrain (site plan).

- Air temperature outdoors at the time of measurements.

- Cloud cover (precipitation) and information on moisture on the surface of parts of the building.

- Pressure difference over the exterior surfaces enclosing the building is measured e.g. with a U-tube manometer. Measurements should be made on each level both on the windward and the leeward side of the building. (Whenever possible, a negative pressure should be created in the building, e.g. by means of an existing fan.)

- The emittance of the surface materials (e-value).

- Air flow and heat radiation conditions in the room.

- Existence of permanent piping and hot radiators (should be shut off, if possible, prior to thermography).

- Indoor air temperature during the course of the measurements.

- Reference temperature for determination of temperature differences in the heat image.

9.2.2. Thermography

The heat camera is set up and turned on (should be activated for a few minutes prior to the measurement). The function and adjustments of the camera are controlled, whereby the directions of the manufacturer are to be followed.

An exploratory overview of the warm surface of the building surface is made. The appropriate sensitivity range of the heat camera is selected. The same sensitivity range should be retained as far as possible in order to facilitate comparisons between various portions of the same building. When selected surface areas are studied in detail, one should, however, select a sensitivity that is sufficient for discovering detectable contrasts in the heat image. Selected portions of the object (both acceptable portions and portions with suspected deficiencies) are to be documented by photographing the heat image (thermograms are obtained). For each surface portion, one should usually obtain one grey-tone image and one isotherm image. Isotherms are located to acceptable areas (surface portions with "normal" surface temperature) and to portions with suspected deficiencies or cold bridges. Thereby, the lower isotherm value should correspond to a characteristic part of the cooled surface (not always the lowest surface temperature). The extent of the cooled area is to be recorded. The locations of thermograms should be recorded, e.g. on the drawing. The interpretation and evaluation of the heat images follows according to the methodology indicated in section 4.2.

If the appearance of the thermogram indicates air leakage, this is to be verified by air speed measurement. Hereby, the speed of leaking air is measured at the leakage point, e.g. with a hot thread anemometer. The measured values should be characteristic for the leakage in the heat image. The proportion of joint or connection where leakage occurs should be estimated.

In order to facilitate subsequent reporting, the thermograms obtained can be mounted on specially designed picutre pages, according to examples shown in the Appendix, page 208.

9.2.3. Reporting

A thermography report should contain the following items:

- Construction of the building (walls, beam tiers, connections).

- Type of surface material (e-value).

- Orientation of the building (site plan) and surrounding buildings and terrain.

- The purpose of the investigation.
- Air temperature conditions at the time of thermography and during 24 hours prior to the measurements.
- Sun radiation conditions during 12 hours before and after the measurements.
- Wind conditions at the time of measurement.
- Pressure drop over the building portion.
- Plan sketch (drawing) of the investigated building with indication of the location of the surface areas presented in the thermograms.
- Thermogram with indication of location and with comments on selected portions of the selected surface areas in the building.
- Interpretation of the thermograms with an evaluation of the insulation and tightness performance of the various construction components.
- Brief analysis of observed insulation deficiencies, in respect to type and extent in the various construction parts.

Normally, the reporting of a thermography investigation is made by means of thermograms with real measuring values in combination with analysis and interpretation of the thermograms and evaluation of the insulation and tightness performace of the building portions.

The measuring results can be subdivided according to the following:

1. Thermograms showing the distribution of surface temperatures in different parts of the building. In conjunction with the thermogram, certain data should be included, such as air temperatures, pressure differences, reference temperatures, air speeds, etc. A brief evaluation of the type and extent of deficiencies is made for the building portion in question. The extent is indicated with a percentage figure showing the proportion of the surface which is cooled, or, the proportion of the joint/connection that leaks air. The percentage may refer to a specific space unit. The surface temperatures or air speeds that are included should be representative of the thermographed building portion.

2. Comments on measured temperature distribution, if this is expected or abnormal. It should be evaluated, whether potential irregularities of the temperature distribution are caused by construction cold bridge, insulation deficiency, or air leakage. The type of deficiency should be identified in respect to type and extent.

3. Summary concerning the function of the heat insulation and air tightness of the various building portions, qualitative evaluation of the insulation and tightness execution of the building. The workmanship is to be evaluated.

The report should also contain an evaluation of the effect of the deficiencies on the energy consumption and indoor climate of the building as well as actions that should be taken. The rationale of such an evaluation is to be included.

## 10. THE DEVELOPMENT OF THERMOGRAPHY

The first field investigations with heat camera were performed in 1968. Svenska Riksbyggen and the national testing institute [Statens provningsanstalt] performed certain orientation measurements with the purpose of clarifying the usefulness of the method. Developmental work was performed at the testing institute in order to define the preconditions for thermography of buildings and to suggest rules for interpretation of heat images. Part of the work has been reported in the construction research report "Thermography of buildings" [12], which was published in 1972.

The present investigation has been performed with the purpose of determining the usefulness and reliability of the heat camera in the field and of defining the methods of building thermography for routine field applications.

The interest in thermography activities has increased markedly during the past few years. It has become increasingly common to require thermography in contract documents and to use the method in disputes between buyers and sellers. Svensk Byggnorm [Swedish Building Standard] 1975 recommends use of heat camera for specific checking of insulation and tightness of buildings.

Thermography has proven a useful and reliable method of investigating the insulation and tightness performance of a building, if applied in the proper way. Builders and construction companies can achieve significant savings by using thermography in the building control. The method can be applied for investigations in conjunction with development of new products and materials. Thermography gives the building owner a possibility to obtain a sort of declaration that his building meets the specified insulation and tightness characteristics.

Most probably, the method will become very important as part of the testimonial process in court cases. In the future, the method would be expected to be increasingly applied, e.g. due to new requirements concerning energy management of buildings, and the development in the energy supply area.

The field activities with heat camera for 1978 include 3-4 field tests by each one of the test institute and Riksbyggen, Inc. Each group consists of two persons (measuring expert and assistant) and is equipped with a heat camera and necessary auxiliary equipment. It is the intention to increase the activities by additional field groups in the years to come. Currently, some 15 consulting organizations are active in the field of building thermography in Sweden.

The increased need for testing and control by means of thermography poses severe requirements on methodology and application, see section 10.1 "Swedish Standard". Rules for authorization of enterprises working with thermography of guildings have been formulated, see section 10.2.

Thermography has also been introduced in other countries, where the interest in the method has been great. This has led to international contacts with both research institutions and national authorities and enterprises, e.g. in the U.S.A., Canada, France, the Soviet Union, and Germany.

## 10.1. Swedish Standard

In order to create the preconditions for uniform and correct application of the thermography method, the testing insitute has cooperated in formulation of the Swedish Standard (SIS 024210) effective November 15, 1977. The standard defines, e.g. the instrument and the application area as well as the requirements on measuring conditions which should be fulfilled for thermography of buildings. Furthermore, rules for interpretation and evaluation of thermograms are discussed. The base material has been obtained from our investigations.

As has been pointed out earlier, the requirements need not be so severe as expressed in the standard, if the camera is used merely for search for air leakages. It would be possible to subdivide heat camera investigations into two methods - one more detailed and one more superficial - according to the following:

A. Thermography for the purpose of investigating insulation and tightness performance of buildings in accordance with the Swedish Standard.

B. Heat camera investigation with the purpose of only locating air leakages in the climate barrier of the building. Here, the basic preconditions are sufficiently great temperature and pressure differences for detecting air leakages through the construction. This more superficial method has also been indicated in the standard.

It should be emphasized that the standard is optional and that in practice, the thermography will be used for various types of efforts, e.g. the following:

1. For specific control of air tightness and heat insulation of buildings, in accordance with the guidelines included in the comments to SBN 1977:3.

2. As required in contract documents, etc.

3. In legal disputes between buyer and seller of a building.

4. For follow-up of insulation and tightness execution during construction. Detail checking. Control of improvement actions taken, etc.

5. To locate air leakages only, e.g. in combination with pressure measurements.

6. In existing buildings, where action is to be taken in conjunction with new requirements for good energy management, and in case of remodeling.

Primarily, thermography according to Swedish Standard should be applied for 1, 2, and 3. Deviations from the standards may naturally be permissible, e.g. for specific measurements according to 4, 5, and 6.

## 10.2. Authorization for thermography study of buildings

Thermography requires specific competency of the measurement personnel. The method has inherent evaluation components which require knowledge and experience within the areas of construction technology, construction physics, heating, water, and sanitary technology, and current measurement techniques. Application of the method may also require supplementary investigations, primarily for quantitative determination of heat resistance in a building portion and for determination of the air tightness of the building.

In order to create the preconditions for correct application of the thermography method, rules for authorization for thermography of buildings have been formulated at the national testing institute. The exact formulation of the authorization rules can be found in the "Regulations for authorized test site for thermography of buildings, included in the law text collection SPFS 1978:2.

The responsibility of the testing institute is to supervise the activities at an authorized test side (APP).

Authorization requires education and study activities. Thus, the testing institute has designed courses with the goal of training measurement experts for thermography at APPs. The purpose is to impart required knowledge in the areas that are involved.

The authorization system is expected to increase trust in and use of thermography for control of insulation and tightness performance of buildings. The authorization is also valuable in evaluating the competency of the thermography consultant.

In the fall of 1978, the testing institute issued the first authorizations.

## 10.3. Work within "Nordtest" and ISO

In the Scandinavian countries, the Swedish Standard has been accepted for the time being as "Nordtest" method.

In a meeting in Stockholm in April of 1976, it was suggested that the thermography method described here be accepted as international standard. The method and the principle for thermography would be clarified, the measurement conditions should be precisely defined, and rules for interpretation and evaluation should be formulated.

At an ISO meeting in Berlin, in May of 1977, a task force was formed for the thermography method. This group has members from France, Germany, Austria, Italy, USA, and Sweden. The task force has now presented a preliminary draft for international standards, which will be discussed at an ISO meeting in the fall of 1978.

## 11. APPENDIX

FIGURE 125 shows the appearance of the thermogram (heat image) for different adjustments of the heat camera.

FIGURE 126 shows the calibration diagram for the range from + 5°C to + 25°C for the model AGA THV 750, with inserted application example. The diagram is prepared specifically for the heat camera used.

FIGURE 127 shows diagrams of the saturation temperature of the air for various air temperatures and relative humidity.

FIGURE 128 shows a form for mounting thermograms when results are to be reported.

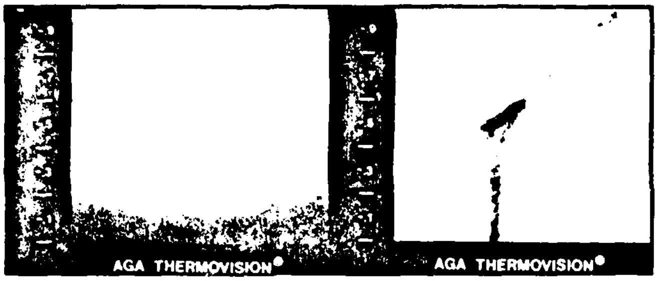
On page 208, a form is shown which can be used for mounting thermograms for reporting purposes.

Table 17 contains the emittance of some common surface materials. The emission figure is determined by means of the heat camera.

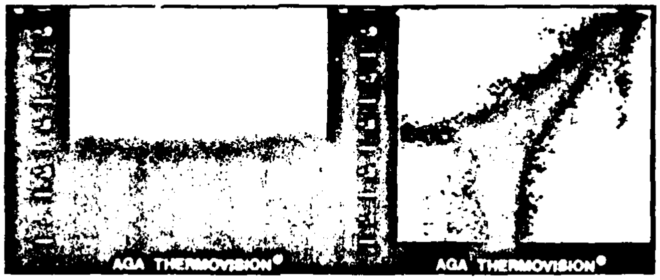
Tables 18 - 21 contain physical data for some construction materials.

FIGURE 125: Examples of variations in the appearance of thermograms depending on different adjustments of the grey scale.

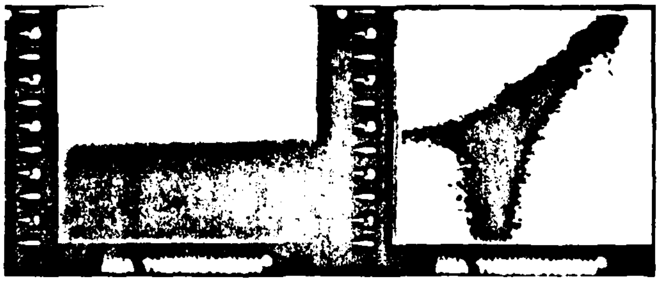
a) Too little contrast. b) Too much contrast.
c) Too much contrast and light. d) Correct adjustment and grey scale.



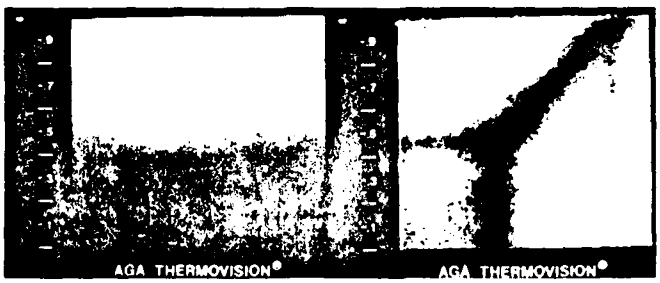

a) För låg kontrast.




b) För hög kontrast.



c) För hög kontrast och ljushet.




d) Rätt inställning och graskala.

**FIGURE 126:** Calibration diagram in the 273 - 303 K range (0 - 30°C) for AGA THV 750 (aperture f/1:8) with inserted example.

Top left of figure: f, T; isotherm units.
Bottom right of figure: Temperature, °C.

Example (see equation 3.2):

$T_2$ = 295 K (=22°C), temperature at measuring point 2.
$f(T_2)$ = 22.0 isotherm units
$\Delta I_{12}$ = 3.8 isotherm units
$\frac{c}{\epsilon}$ = 0.9
$f(T_1)$ = 17.8 isotherm units
$T_1$ = 289 K (=16°C), temperature at measuring

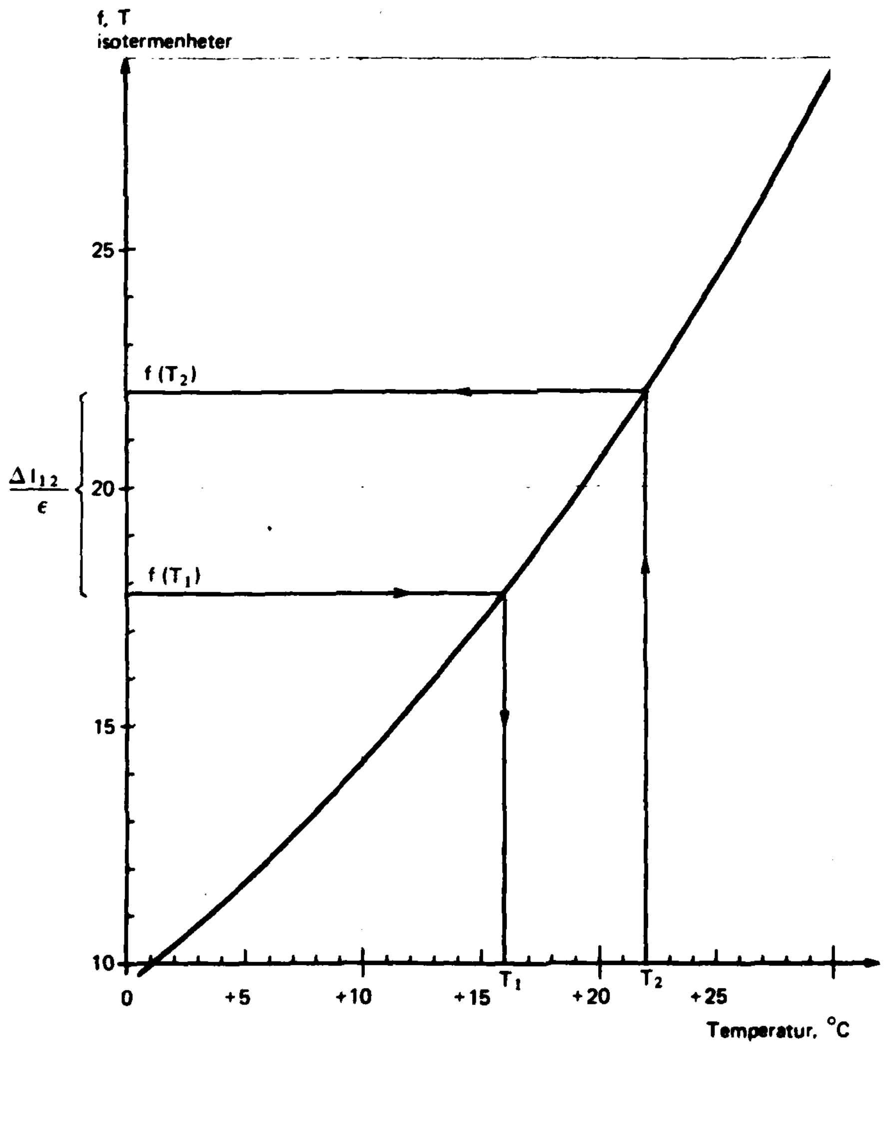


**FIGURE 127:** Saturation temperature of the air at varying relative humidity and air temperature.

Top left in figure: Saturation temperature of the air, °C
Top right in figure: Relative humidity, %
Bottom right in figure: Air temperature, °C.

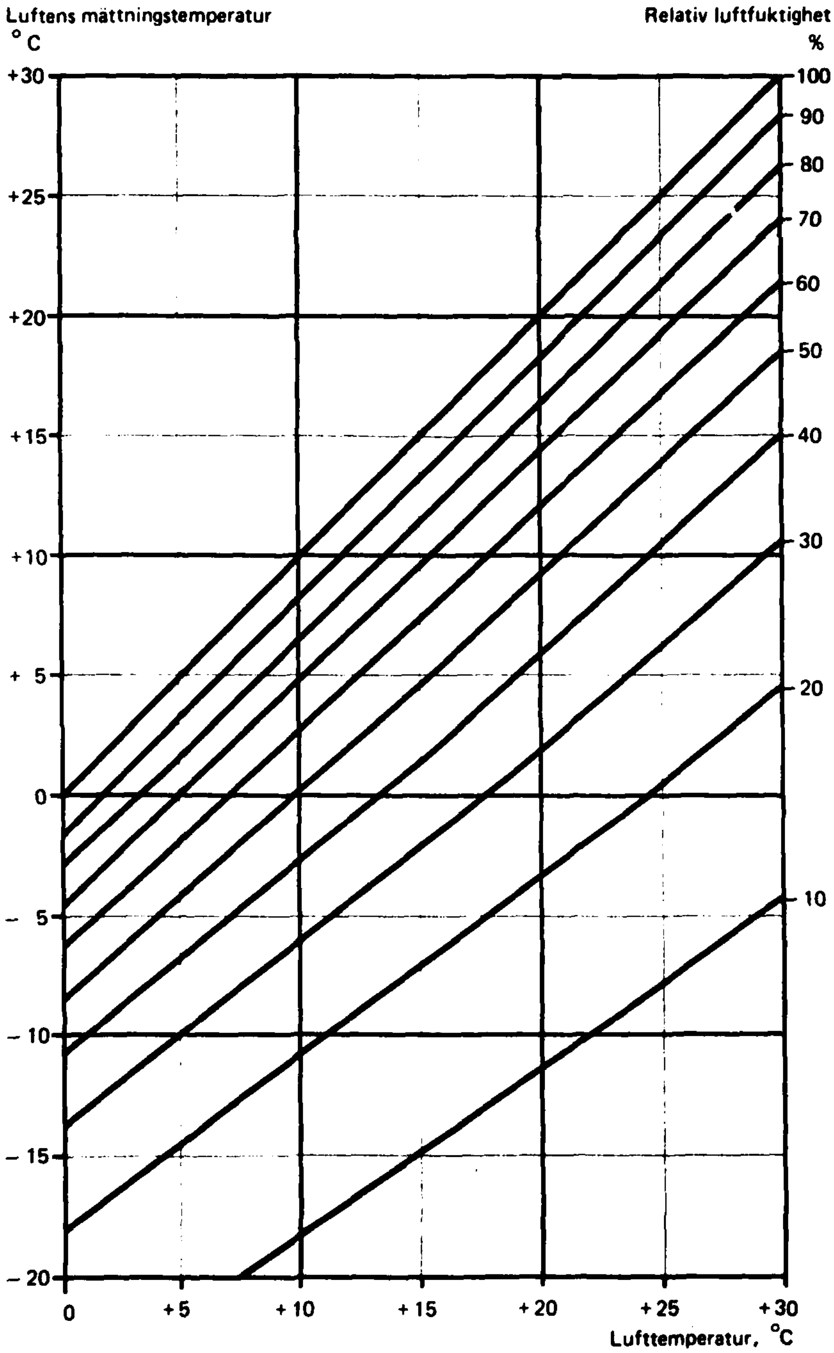
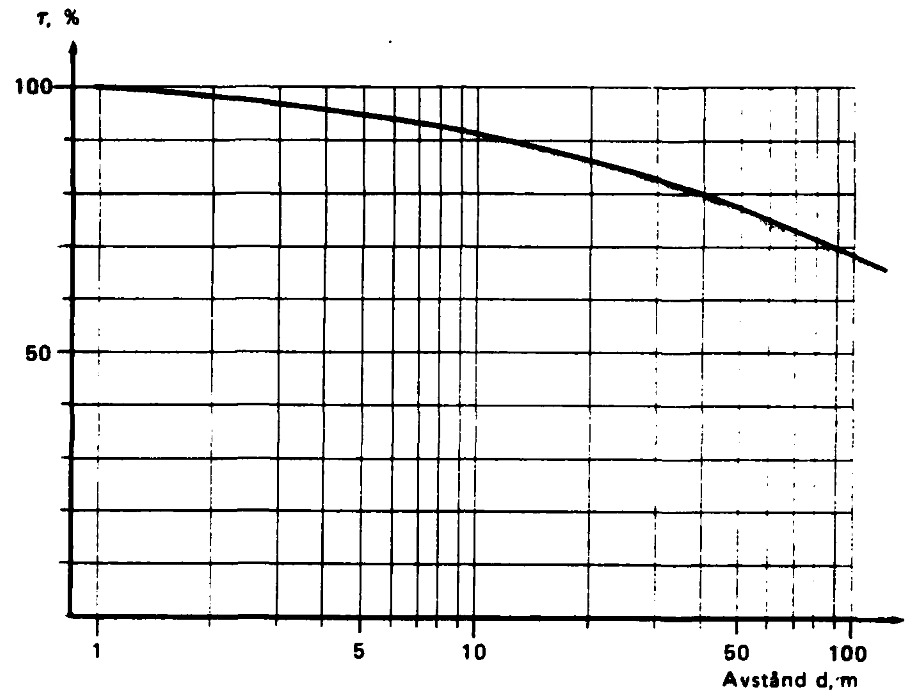


**FIGURE 128:** Transmission (r) for radiation in air as a function of the distance (Typical curve)

Bottom right of figure: Distance d, m.



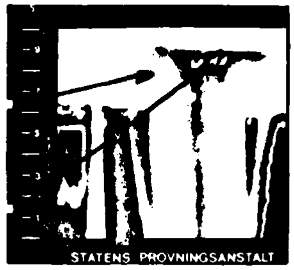
**Reporting form:**

**OBJECT: Single family dwelling, designation 1:273.**

**Appendix 1**
**Certificate No.**

GREY TONE IMAGE NO. 1

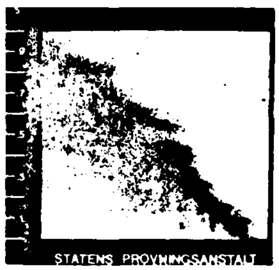

ISOTHERM IMAGE NO. 2

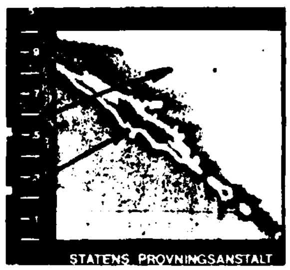



House/~~apt~~ 1
Ceiling corner, liv. room
p A
$t_u$ -6; $t_i$ +25; $t_r$ +24
$t_i - t_u$ 31; $\Delta$ p -5
$\Delta$ I -2.5; $\Delta$ t 3.5
v $\approx$0.2 (at ceiling angle)

| | | |
|---|---|---|
| | EXPECTED - EVEN TEMPERATURE DISTRIBUTION OF SURFACE PORTION AT | |
| X | COOLED PORTIONS AT ceiling angle (air leakage) | ( $\approx$ 30%) |
| | COOLED PORTIONS AT CONNECTION BETWEEN OUTSIDE WALL AND | ( %) |
| | AIR LEAKAGE THROUGH JOINT BETWEEN WARM WALL AND FRAME | ( %) |

GREY TONE IMAGE NO. 3



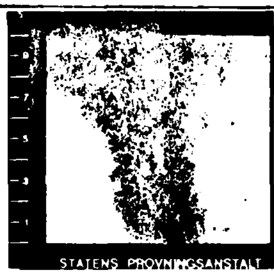



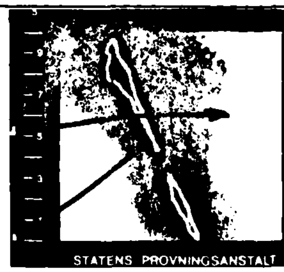

ISOTHERM IMAGE NO. 4

Hus/~~apt~~
Ceiling corner, liv.room
p B
$t_u$ -6; $t_i$ +25; $t_r$ +24
$t_i - t_u$ 31; $\Delta$p - 5
$\Delta$ I -1.4; $\Delta$ t 2.0
v 0

| | | |
|---|---|---|
| | EXPECTED - EVEN TEMPERATURE DISTRIBUTION OF SURFACE PORTION AT | |
| X | COOLED PORTIONS AT ceiling (beam tier connection) due to insulation deficiency | ( $\approx$ 30%) |
| | COOLED PORTIONS AT CONNECTION BETWEEN OUTSIDE WALL AND | ( %) |
| | AIR LEAKAGE THROUGH JOINT BETWEEN WARM WALL AND FRAME | ( %) |

GREY TONE IMAGE NO. 5




ISOTHERM IMAGE NO. 6

House/apt
Floor angle, liv. room
p C
$t_u$ -6; $t_i$ +25; $t_r$ +23
$t_i - t_u$ 31; $\Delta$p -5
$\Delta$I -2.5; $\Delta$ t 4.0
v 0.2-0.3
(at floor angle)

| | | |
|---|---|---|
| | EXPECTED - EVEN TEMPERATURE DISTRIBUTION OF SURFACE PORTION AT | |
| X | COOLED PORTIONS AT floor angle (air leakage) | ($\approx$ 40%) |
| | COOLED PORTIONS AT CONNECTION BETWEEN OUTSIDE WALL AND | ( %) |
| | AIR LEAKAGE THROUGH JOINT BETWEEN WARM WALL AND FRAME | ( %) |

TABLE 17: Emission figures, within the wavelength range 2 - 5.6 μm for some common surface materials [12].

| Surface material | Emission figure |
|---|---|
| Wood fiber panel (porous), untreated | 0.85 |
| Wood fiber panel (hard), untreated | 0.85 |
| Plywood, untreated | 0.83 |
| Pine (planed), untreated | 0.83 |
| Pine (not planed), untreated | 0.84 |
| Gypsum panel, untreated | 0.90 |
| Particle board, untreated | 0.90 |
| Sanding/spackling compound, white | 0.88 |
| Oil paint, grey, matte | 0.97 |
| Oil paint, grey, glossy | 0.96 |
| Oil paint, black, matte | 0.94 |
| Oil paint, black, glossy | 0.92 |
| Plastic based paint, white | 0.84 |
| Plastic based paint, black | 0.95 |
| "Kaduvin" lacquer, matte | 0.93 |
| Wallpaper (lightly patterned), light grey | 0.85 |
| Wallpaper (lightly patterned), red | 0.90 |
| Plasticized wallpaper, white | 0.84 |
| Plasticized wallpaper, red | 0.94 |
| Burlap, natural color | 0.87 |
| Burlap, green | 0.88 |
| Brick facing, red | 0.92 |
| Brick facing, yellow | 0.72 |
| Plaster, grey | 0.92 |

TABLE 18: From the Comments to the SBN 1977:3

Table B 33.1 c Practically applicable heat conductivity $\lambda_n$ for certain other construction materials.

| Material | Density<br>p torr<br>$kg/m^3$ | Average heat conductivity for dry material $\lambda_{10}$<br>W/m °C | Moisture quotient<br>$u_n$<br>% | Practically applicable heat conductivity $\lambda_n$<br>W/m °C |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| Asbestos cement panels | 1,800 | 0.40 | 2 | 0.60 |
| Asbestos silicate panels | 800 | 0.13 | 4 | 0.19 |
| | 660 | 0.12 | 4 | 0.18 |
| Asphalt | | | | |
| pouring asphalt | 2,100 | | | 0.8 |
| bituminous | 1,050 | | | 0.18 |
| Window glass | 2,600 | | | 0.8 |
| Wood (heat flow perpendicular to the fibers) | | | | |
| pine, spruce | 500 | 0.12 | 16 | 0.14 |
| Beech, oak | 700 | 0.14 | 18 | 0.16 |
| Particle boards | 600 | 0.13 | 10 | 0.14 |
| | 400 | 0.11 | 10 | 0.12 |
| Inside wood-wool panels with sealing surface layer | 151-200 | | 8 | 0.075 |
| | 201-300 | | 8 | 0.075 |
| | 301-350 | | 8 | 0.080 |
| without sealing surface layer | 151-200 | | 8 | 0.075 |
| Horizontally applied | 201-300 | | 8 | 0.075 |
| at downward heat flow | 301-350 | | 8 | 0.080 |
| without sealing layer | 151-200 | | 8 | 0.095 |
| other uses | 201-300 | | 8 | 0.075 |
| | 301-350 | | 8 | 0.085 |
| Wood fiber panels | | | | |
| hard | 1,000 | 0.12 | 8 | 0.13 |
| semi-hard | 600 | 0.075 | 9 | 0.080 |
| porous | 300 | 0.045 | 10 | 0.050 |
| asphalt impregnated | 400 | 0.055 | 10 | 0.065 |

TABLE 19: From Comments to SBN 1977:3

Table B 33.1 d Practically applicable heat conductivity, $\lambda_n$ for filling material

| Material | Density $\rho$ torr kg/m$^3$ | Average heat conductivity for dry material $\lambda$ 10 W/m °C | Moisture quotient $u_n$ % | Practically applicable heat conductivity $\lambda_n$ W/m °C |
|---|---|---|---|---|
| Filling | | | | |
| sand | 1,700 | | 0.5 | 0.40 |
| slate ashes | 1,000 | | 2 | 0.25 |
| coke ashes | 700 | | 3 | 0.25 |
| crushed gas concrete | 400 | | 4 | 0.15 |
| Light clinker in beam tier unventilated | 450 | 0.10 | 0.5 | 0.13 |
| | 330 | 0.09 | 0.5 | 0.10 |
| | 280 | 0.08 | 0.5 | 0.09 |
| in beam tier ventilated | 330 | 0.09 | 0.5 | 0.12 |
| on ground, unventilated | 330 | 0.09 | 6 | 0.13 |
| | 280 | 0.08 | 6 | 0.12 |
| Granulated furnace slag | 250 | | 0.5 | 0.12 |
| | 150 | | 0.5 | 0.10 |
| Sawdust, loose | 120 | | 12 | 0.12 |
| packed | 200 | | 12 | 0.18 |
| Cutter shavings loose | 80 | | 12 | 0.14 |
| packed | 120 | | 12 | 0.08 |
| Polystyrene cellular plastic, packed pellets on beam tiers | 10-20 | | 2 | 0.06 |
| Carbamide cellular plastic | 7-14 | | | g |

TABLE 18 (Cont.)

| | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Cork tiles, expanding | 200 | 0.040 | 3 | 0.046 |
| | 140 | 0.035 | 3 | 0.040 |
| Cork parquet | 500 | 0.075 | 10 | 0.050 |
| Straw panels, inside | 300 | 0.085 | 10 | 0.090 |
| Cell glass[?] | 180 | 0.060 | | 0.065 |
| " " | 150 | 0.055 | | 0.060 |
| " " | 130 | 0.050 | | 0.055 |
| Mineral wool fiber panels | 400 | 0.040 | 1 | 0.050 |
| Mineral wool | 15-200 | | 0.5 | 0.055 |
| Styrene cellular plastic | 12-40 | | 2 | 0.055 |
| Urethanel cellular plastic | 30-50 | | | 0.040 |

TABLE 20: From Comments to SBN 1977:3

Table B 33.1 e Practically applicable heat conductivity for officially quality controlled heat insulation materials

| Material Construction type | Quality group for insulation material | Average heat conductivity for dry material $\lambda_{10}$ W/m °C | Moisture quotient $u_n$ % | Practically applicable heat conductivity $\lambda_n$ W/m °C |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| Cell glass | | | | |
| panels laid in | C | k | - | 0.052 |
| asphalt, joints | D | | - | 0.057 |
| max. 1 mm | E | | - | 0.062 |
| Styrene cellular plastic | | | | |
| panels glued or | A | k | 2 | 0.039 |
| poured against | B | | 2 | 0.043 |
| tight material layer above ground | C | | 2 | 0.048 |
| other use above | A | | 2 | 0.040 |
| ground | B | | 2 | 0.045 |
| | C | | 2 | 0.051 |
| panels applied between slab and drained soil | A | | 2 | 0.042 |
| Mineral wool | | | | |
| hard panels glued or poured against tight material above ground | A | k | 0.5 | 0.038 |
| Other application | A | | 0.5 | 0.040 |
| above ground | B | | 0.5 | 0.045 |
| | C | | 0.5 | 0.051 |
| hard panels applied between foundation and drained soil | A | | 1.0 | 0.060 |
| hard panels pplied between floor slab and drained soil | A | | 0.5 | 0.042 |
| Gas concrete | | | | |
| insulation panels | 400 | k | 4 | 0.10 |
| inside and outside | 450 | | 4 | 0.12 |
| with rain cap | 500 | | 4 | 0.14 |
| | 600 | | 4 | 0.17 |

TABLE 20 (Cont.)

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| outdoors, above ground | 400 | | 6 | 0.11 |
| | 450 | | 6 | 0.13 |
| | 500 | | 6 | 0.15 |
| | 600 | | 6 | 0.18 |
| Outdoors, under ground | 500 | | 30 | 0.24 |
| | 600 | | 30 | 0.27 |

TABLE 21: From Comments to SBN 1977:3

Table B 33.1 e (Cont.)

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Elements | | | | |
| Outside walls with rain capping | 400 | | 4 | 0.10 |
| | 450 | | 4 | 0.12 |
| | 500 | | 4 | 0.14 |
| outside walls | 400 | | 6 | 0.11 |
| | 450 | | 6 | 0.13 |
| | 500 | | 6 | 0.15 |
| outside walls below ground | 500 | | 15 | 0.18 |
| Outside walls below ground with capillary disruption but not diffusion preventing material layer, outside | 500 | | 10 | 0.16 |
| roofs and beam tiers over dry spaces | 450 | | 4 | 0.12 |
| | 500 | | 4 | 0.14 |
| beam tiers above crawl spaces | 500 | | 6 | 0.15 |
| Masonry with gas concrete | | | | |
| Masonry with rain capping | 400 | | 4 | 0.17 |
| | 450 | | 4 | 0.19 |
| | 500 | | 4 | 0.21 |
| wall above ground | 400 | | 6 | 0.15 |
| | 450 | | 6 | 0.19 |
| | 500 | | 6 | 0,21 |
| wall below grade | 500 | | 15 | 0.24 |
| | 600 | | 15 | 0.27 |

TABLE 21: From Comments to SBN 1977:3 (Cont.)

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| wall below grade with capillary disruption but not diffusion preventing material, outside | 500 | | 10 | 0.23 |
| | 600 | | 10 | 0.26 |
| thin joint wall and glued wall with rain capping | 400 | | 4 | 0.12 |
| | 450 | | 4 | 0.14 |
| | 500 | | 4 | 0.16 |
| thin joint wall and glued wall above ground | 400 | | 6 | 0.12 |
| | 450 | | 6 | 0.14 |
| | 500 | | 6 | 0.16 |
| | 600 | | 6 | 0.19 |
| thin joint wall and glued wall below grade | 500 | | 15 | 0.19 |
| | 600 | | 15 | 0.22 |
| thin joint wall and glued wall below grade with capillary disruption but not diffusion preventing material, outside | 500 | | 10 | 0.18 |
| | 600 | | 10 | 0.20 |

## 12. LITERATURE


1. Adamsson, B., 1974: Energikonsumtion för lokalkomfort och hushåll [Energy consumption for local comfort and households]. Course material in conjunction with course "Rational energy usage by means of improved construction and installation technology" arranged by STF enginnering education program October 17-18, 1974, Stockholm.

2. Andreasson, S. and Gustafsson, D., 1971: Luftrörelser vid byggnader [Air movements around buildings]. (Institute for building construction technology, LTH). Handbook in construction technology. Lund.

3. ASHRAE Handbook of Fundamentals, 1967, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., New York.

4. Bankvall, C., 1969: Temperaturbestämning av värmeisoleringsundersökning genom strålningsmätning [Temperature determination in heat insulation investigation by means of radiation measurement]. (Institute of construction technology, LTH). Report 11. Lund.

5. Brown, G., 1959: Ytterväggars värmeisoleringsförmåga [Heat insulation capacity of outside walls]. National office of construction research. Stockholm.

6. Clark, J.A., 1963: Theory and Fundamental Research in Heat Transfer. Pergamon Press, Oxford.

7. FOA orienterar om infrarödteknik [FOA informs on infrared techniques], No. 11. Defense research institute, Stockholm.

8. Kommentarer till Svensk Byggnorm, 1977:3 [Comments to Swedish Construction Standards, 1977:3]: Energihushållning m.m. [Energy management etc.] National institute of planning. Stockholm.

9. Love, T.J., 1968: Radiative heat transfer. Charles E. Merrill Publishing Company, Columbus, OH.

10. Nevander, L.-E. and Bankvall, C., 1968: Värme [Heat]. (Institute of construction technology, LTH). Handbook in construction technology. Lund.

11. Operating Manual AGA Thermovision System 680/102B. AGA, Lidingö.

12. Paljak, I. and Pettersson, B., 1972: Termografering av byggnader [Thermography of buildings]. Building research. Stockholm.

13. Pettersson, B., 1976. Lokalisering av isolerfel och luftläckage i byggnader med hjälp av IR kamera [Locating insulation deficiencies and air leakage in buildings by means of IR camera]. National testing institute, SP-RAPP 1976:15. Stockholm.

14. Rapport avseende energiförbrukningens utveckling 1973-1976 samt prognos för 1977 [Report concerning the development of energy consumption 1973-1976 and prognosis for 1977]. Energy savings committe. Stockholm.

15. Sparrow, E.M. and Cess, R.D., 1967: Radiation and heat transfer. Brooks/Cole Publishing Company, Belmont, CA.

16. Svensk Byggnorm 1975 [Swedish Construction Standard 1975], 3rd ed. National planning office. Stockholm.

17. Tanura, G.T. and Wilson, A.G., 1964: Air leakage and pressure measurements on two occupied houses. ASHRAE Transactions, Vol. 72, New York.

18. Wolfe, W.L., 1965: Handbook of military infrared technology. (US Government Printing Office). Washington, DC.

19. Svensk Standard, SIS 024210, 1977: Värmeisolering - Termografering av byggnader [Swedish Standard, SIS 024210, 1977: Heat Insulation - Thermography of buildings]. (Sweden's standardization commission), 1st ed. Stockholm.

20. Taesler, R., 1972: Klimatdata för Sverige [Climate data for Sweden]. Building research T2:1972. Stockholm.

21. EFUD 78, Energiprogram för forskning, utredning, demonstration [EFUD 78: Energy program for research, investigation, demonstration]. SOU 1977:56. Stockholm.

Other literature:

Bankvall, C., Pettersson, B., and Samuelsson, I., 1978: Fältprovning i samband med byggnaders energiförbrukning [Field testing in conjunction with the energy consumption of buildings]. National testing institute, report SP-RAPP 1978:6. Borås.

Pettersson, B., 1978: Fältprovning av byggnaders värmeisolering och lufttäthet [Field testing of the heat insulation and air tightness of buildings]. Technical report SP-RAPP 1978:11. National testing institue, Borås.

Pettersson, B., 1978: Infrared thermography and thermal insulation in buildings. Technical report 1978:22. National testing institute, Borås.

Statens provningsanstalts författningssamling, 1978. Föreskrifter för auktoriserad provplats för termografering av byggnader [National testing institute, collection of regulations, 1978. Regulations concerning authorized test location for thermography of buildings.] National testing institute, SPFS 1978:2, Borås.

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